OIPE JC16
OCT 0 6 2003
PATENT & TRADEMARK OFFICE

2152
#6 SP
10-10-03

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Application No.	09/990,569
Filing Date	November 21, 2001
First Named Inventor	Aaron S. Mar
Art Unit	2152
Examiner Name	
Total Number of Pages in This Submission	66
Attorney Docket Number	4906P055

RECEIVED
OCT 0 8 2003
Technology Center 2100

ENCLOSURES *(check all that apply)*

- ☐ Fee Transmittal Form
  - ☐ Fee Attached
- ☐ Amendment / Response
  - ☐ After Final
  - ☐ Affidavits/declaration(s)
- ☐ Extension of Time Request
- ☐ Express Abandonment Request
- ☐ Information Disclosure Statement
  - ☐ PTO/SB/08
- ☒ Certified Copy of Priority Document(s)
- ☐ Response to Missing Parts/ Incomplete Application
  - ☐ Basic Filing Fee
  - ☐ Declaration/POA
- ☐ Response to Missing Parts under 37 CFR 1.52 or 1.53
- ☐ Drawing(s)
- ☐ Licensing-related Papers
- ☐ Petition
- ☐ Petition to Convert a Provisional Application
- ☐ Power of Attorney, Revocation Change of Correspondence Address
- ☐ Terminal Disclaimer
- ☐ Request for Refund
- ☐ CD, Number of CD(s)
- ☐ After Allowance Communication to Group
- ☐ Appeal Communication to Board of Appeals and Interferences
- ☐ Appeal Communication to Group (Appeal Notice, Brief, Reply Brief)
- ☐ Proprietary Information
- ☐ Status Letter
- ☒ Other Enclosure(s) *(please identify below):*

Request for Priority

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm *or* Individual name	Daniel M. DeVos, Reg. No. 37,813 BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN LLP
Signature	
Date	10/3/03

CERTIFICATE OF MAILING/TRANSMISSION

I hereby certify that this correspondence is being deposited with the United States Postal Service on the date shown below with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

Typed or printed name	Jane Wolfe		
Signature		Date	10-3-03

OIPE
OCT 0 6 2003
PATENT & TRADEMARK OFFICE

DOCKET NO.: 4906P055

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of:

AARON S. MAR

Application No.: 09/990,569

Filed: November 21, 2001

For: **Policy Change Characterization Method and Apparatus**

Art Group: 2152

Examiner:

RECEIVED
OCT 0 8 2003
Technology Center 2100

Commissioner for Patents
P.O, Box 1450
Alexandria, VA 22313-1450

REQUEST FOR PRIORITY

Applicant respectfully requests a convention priority for the above-captioned application, namely:

COUNTRY	APPLICATION NUMBER	DATE OF FILING
Canada	2,326,851	24 November 2000

☒ A certified copy of the document is being submitted herewith.

Respectfully submitted,

Blakely, Sokoloff, Taylor & Zafman LLP

Dated: _____

_____

Daniel M. DeVos, Reg. No. 37,813

I hereby certify that this correspondence is being deposited with the United States Postal Service on the date shown below with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

Jane Wolfe 10-3-03

Jane Wolfe *Date*

12400 Wilshire Blvd., 7th Floor
Los Angeles, California 90025
Telephone: (408) 720-8300

Office de la propriété intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An Agency of Industry Canada

Bureau canadien des brevets

Certification

Canadian Patent Office

Certification

La présente atteste que les documents ci-joints, dont la liste figure ci-dessous, sont des copies authentiques des documents déposés au Bureau des brevets.

This is to certify that the documents attached hereto and identified below are true copies of the documents on file in the Patent Office.

Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,326,851,** on November 24, 2000, by **REDBACK NETWORKS SYSTEMS CANADA INC.,** assignee of Aaron Mar, for "Policy Change Characterization Method and Apparatus".

CERTIFIED COPY OF PRIORITY DOCUMENT

Gracy Paulhus
Agent certificateur/Certifying Officer

August 12, 2003
Date

Canada

(CIPO 68)
04-09-02

OPIC CIPO

POLICY CHANGE CHARACTERIZATION METHOD AND APPARATUS

Field of the Invention

This invention relates to data communication networks. The invention relates to systems for facilitating the configuring of networks to provide desired levels of Quality of Service ("QoS") for data communication services on the networks.

Background of the Invention

Maintaining efficient flow of information over data communication networks is becoming increasingly important in today's economy. Telecommunications networks are evolving toward a connectionless model from a model whereby the networks provide end-to-end connections between specific points. In a network which establishes specific end-to-end connections to service the needs of individual applications, the individual connections can be tailored to provide a desired bandwidth for communications between the end points of the connections. This is not possible in a connectionless network. The connectionless model is desirable because it saves the overhead implicit in setting up connections between pairs of endpoints and also provides opportunities for making more efficient use of the network infrastructure through statistical gains. Many networks today provide connectionless routing of data packets, such as Internet Protocol ("IP") data packets, over a network which includes end-to-end connections for carrying data packets between certain parts of the network. The end-to-end connections may be provided by technologies such as Asynchronous Transfer Mode ("ATM"), Time Division Multiplexing ("TDM") and SONET/SDH.

A Wide Area Network ("WAN") is an example of a network in which the methods of the invention may be applied. WANs are used to provide interconnections capable of carrying many different types of data between geographically separated nodes. For example, the same WAN may be used to transmit video images, voice conversations, e-mail messages, data to and from database servers, and so on. Some of these services place different requirements on the WAN.

A typical WAN comprises a shared network which is connected by access links to two or more geographically separated customer premises. Each of the customer premises may include one or more devices connected to the network. More typically, each

customer premise has a number of computers connected to a local area network ("LAN"). The LAN is connected to the WAN access link at a service point. The service point is generally at a "demarcation" unit or "interface device" which collects data packets from the LAN which are destined for transmission over the WAN and sends those packets across the access link. The demarcation unit also receives data packets coming from the WAN across the access link and forwards those data packets to destinations on the LAN. One type of demarcation unit may be termed an ESP (Enterprise Service Point).

A network service is dependent on the amount of data it can send and receive from a source device to one or more destination devices. Therefore, the quality of a network service is dependent on the amount of network resources (such as uptime, outages, bandwidth, delay, loss, and jitter) it can utilize to transfer its data. However, in a conventional IP network, all network services share all the network resources on a first come, first serve ("best effort") basis. This may be detrimental to some network services since some services require more network resources than other services.

For example, a typical video conferencing service requires much more data to be sent than a typical e-mail service. Transmitting a video signal for a video conference requires fairly large bandwidth, short delay (or "latency"), small jitter, and reasonably small data loss ratio. An e-mail service requires far less network resources than a video conferencing service because the e-mail service often has relatively little data to send to its destinations and it is generally acceptable if an e-mail transmission is slightly delayed in transiting a network. Transmitting e-mail messages or application data can generally be done with lower bandwidth but can tolerate no data loss. Furthermore, it is not usually critical that e-mail be delivered instantly, so e-mail services can usually tolerate longer latencies and lower bandwidth than other services. In addition, the e-mail service requires only enough network resources to send data in a single direction. Conversely, the typical video conferencing service requires enough network resources to send data constantly and seamlessly in two directions. This may be required if all participants in the video conference want to see each other, thus requires an individual's image to be sent to the other participants and the other participant's images to be received.

If the network resources are shared in a best effort fashion between these and other types of network services, the e-mail service will deliver e-mail extremely fast, but the

video conferencing service would not be able to display a very clear picture. What is desired is to have a policy where the network resources utilization is weighted such that the video conferencing service receives more network resources than e-mail services.

Typically, an enterprise which wishes to link its operations by a WAN obtains an unallocated pool of bandwidth for use in carrying data over the WAN. While it is possible to vary the amount of bandwidth available in the pool (by purchasing more bandwidth on an as-needed basis), there is no control over how much of the available bandwidth is taken by each application.

Again, guaranteeing the Quality of Service needed by applications which require low latency is typically done by dedicating end-to-end connection-oriented links to each application. This tends to result in an inefficient allocation of bandwidth. Network resources which are committed to a specific link are not readily shared, even if there are times when the link is not using all of the resources which have been allocated to it. Thus committing resources to specific end-to-end links reduces or eliminates the ability to achieve statistical gains. Statistical gains arise from the fact that it is very unlikely that every application on a network will be generating a maximum amount of network traffic at the same time.

If applications are not provided with dedicated end-to-end connections but share bandwidth, then each application can, in theory, share equally in the available bandwidth. In practice, however, the amount of bandwidth available to each application depends on things such as router configuration, the location(s) where data for each application enters the network, the speeds at which the application can generate the data that it wishes to transmit on the network and so on. The result is that bandwidth may be allocated in a manner that bears no relationship to the requirements of individual applications or to the relative importance of the applications. There are similar inequities in the latencies in the delivery of data packets over the network.

The term "Quality of Service" is used in various different ways by different authors. In general, QoS refers to a set of parameters which describe the required traffic characteristics of a data connection. In this specification, the term "QoS" generally refers to

a set of one or more of the following interrelated parameters which describe the way that a data connection treats data packets generated by an application:

- Minimum Bandwidth - a minimum rate at which a data connection must be capable of forwarding data originating from the application. The data connection might be incapable of forwarding data at a rate faster than the minimum bandwidth but should always be capable of forwarding data at a rate equal to the rate specified by the minimum bandwidth;

- Maximum Delay - a maximum time taken for data from an application to completely traverse the data connection. QoS requirements are met only if data packets traverse the data connection in a time equal to or shorter than the maximum delay;

- Maximum Loss - a maximum fraction of data packets from the application which may not be successfully transmitted across the data connection; and,

- Jitter - a measure of how much variation there is in the delay experienced by different packets from the application being transmitted across the data connection. In an ideal case, where all packets take exactly the same amount of time to traverse the data connection, the jitter is zero. Jitter may be defined, for example, as any one of various statistical measures of the width of a distribution function which expresses the probability that a packet will experience a particular delay in traversing the data connection.

Different applications require different levels of QoS.

Recent developments in core switches for WANs have made it possible to construct WANs capable of quickly and efficiently transmitting vast amounts of data. There is a need for a way to provide network users with control over the QoS provided to different data services which may be provided over the same network.

Service providers who provide access to WANs wish to provide their customers with "Service Level Agreements" rather than raw bandwidth. A Service Level Agreement is an agreement between a service provider and a customer that defines the level of service that will be provided for each particular type of application. This will permit the service providers to take advantage of statistical gain to more efficiently use the network infrastructure while maintaining levels of QoS that customers require. To do this, the service providers need a way to manage and track usage of these different services. There is a particular need for relatively inexpensive apparatus and methods for facilitating the provision of services which take advantage of different levels of QoS.

Applications connected to a network generate packets of data for transmission on the network. In providing different levels of service it is necessary to be able to sort or "classify" data packets from one or more applications into different classes which will be accorded different levels of service. The data packets can then be transmitted in a way which maintains the required QoS for each application. Data packets generated by one or more applications may belong to the same class.

Clearly, sharing all the network resources equally between the network services is not desired by a customer. A set of rules for allocating network resources between the various network services may be called a "policy". Policy management is meant to alleviate the uncontrolled network resources allocation between network services. The ability to configure the allocation of the network resources for the network services is called scheduling-based policy management. Scheduling-based policy management is preferred over priority-based policy management to be the policy architecture. Priority-based policy management means all data packets of a particular network service are given a priority level over all data packets of other network services. Scheduling-based policy management means that each network service is given a configurable amount of network resources over all other network services. A problem with implementing scheduling-based policy management occurs when it becomes necessary to shift between different policies. This may require re-configuring a large number of network devices. There is a need for methods and apparatus which will facilitate efficient change over from one policy to another.

Brief Description of the Drawings

In the attached drawings which illustrate non-limiting embodiments of the invention:

Figure 1 is a schematic view of a wide area network according to the invention which comprises enterprise service point ("ESP") router devices according to the invention;

Figure 2 is a schematic view illustrating two flows in a communications network according to the invention;

Figure 3 is a diagram illustrating the various data fields in a prior art IP v4 data packet;

Figure 4 is a schematic diagram illustrating the structure of a possible policy tree according to the invention;

Figure 5 is a schematic diagram illustrating an example of a possible policy tree according to the invention;

Figure 6 is a schematic diagram illustrating the inheritance nature of classes in a policy tree;

Figure 7 is a schematic diagram illustrating the mapping between a logical policy tree and its compiled or collapsed equivalent;

Figure 8 is a schematic diagram illustrating scheduling classes and flow classes in a policy tree;

Figure 9 is a schematic diagram illustrating how a class is defined and placed in a class repository and later copied into a policy tree;

Figure 10 is a schematic diagram illustrating how a policy is defined and placed in a policy repository and later activated at a termination point;

Figure 11 is a schematic diagram of a logical pipeline illustrating how a data packet is processed;

Figure 12 is a schematic diagram illustrating how a policy is applied to both incoming and outgoing packets;

Figure 13 is a schematic diagram illustrating the organization of logical pipeline components within an ESP; and

Figure 14 is a schematic diagram illustrating how a policy can be put into service over an existing policy using incremental changes.

Detailed Description

This invention may be applied in many different situations where data packets are scheduled and dispatched. The following description discusses the application of the invention to scheduling onward transmission of data packets received at an Enterprise Service Point ("ESP") router device. The invention is not limited to use in connection with ESP devices but can be applied in almost any situation where classified data packets are scheduled and dispatched.

Figure 1 shows a generalized view of a pair of LANs **20**, **21** connected by a WAN **22**. Each LAN **20**, **21** has an Enterprise Service Point unit ("ESP") **24** which connects LANs **20**, **21** to WAN **22** via an access link **26**. LAN **20** may, for example, be an Ethernet network, a token ring network or some other computer installation. Access link **26** may, for example, be an Asynchronous Transfer Mode ("ATM") link. Each LAN has a number of connected devices **28** which are capable of generating and/or receiving data for transmission on the LAN. Devices **28** typically include network-connected computers. The invention is not limited to data communications between LANs and WANs, but can also be applied to data communications between two LANS or two WANs or any other situation where classified data packets are scheduled and dispatched.

As required, various devices **28** on network **20** may establish data connections with devices **28** of network **21** over WAN **22** and vice versa. A single device may be running one or more applications each of which may maintain uni-directional or bi-directional connections to applications on another device **28**. Each connection may be called a session. Each session comprises one or more flows. Each flow is a stream of data from a particular source to a particular destination. For example, Figure 2 illustrates a session between a computer **28A** on network **20** and a computer **28B** on network **21**. The session comprises two flows **32** and **33**. Flow **32** originates at computer **28A** and goes to computer **28B** through WAN **22**. Flow **33** originates at computer **28B** and goes to computer **28A** over WAN **22**. Most typically data in a great number of flows will be passing through each ESP **24** in any period. ESP **24** manages the outgoing flow of data through at least one port and typically through each of two or more ports.

Each flow consists of a series of data packets. In general, the data packets may have different sizes. Each packet comprises a header portion which contains information about the

packet and a payload or datagram. For example, the packets may be Internet protocol ("IP") packets.

Figure 3 illustrates the format of an IP packet 35 according to the currently implemented IP version 4. Packet 35 has a header 36 and a data payload 38. The header contains several fields. The "version" field contains an integer which identifies the version of IP being used. The current IP version is version 4. The "header length" field contains an integer which indicates the length of header 36 in 32-bit words. The "Type of Service" field contains a number which can be used to indicate a level of Quality of Service required by the packet. The "total length" field specifies the total length of packet 35. The "identification" field contains a number which identifies the data in payload 38. This field is used to assemble the fragments of a datagram which has been broken into two or more packets. The "flags" field contains 3 bits which are used to determine whether the packet can be fragmented. The "time-to-live" field contains a number which is decremented as the packet is forwarded. When this number reaches zero the packet may be discarded. The "protocol" field indicates which upper layer protocol applies to packet 35. The "header checksum" field contains a checksum which can be used to verify the integrity of header 36. The "source address" field contains the IP address of the sending node. The "destination address" field contains the IP address of the destination node. The "options" field may contain information related to packet 35.

Each ESP 24 receives streams of packets from its associated LAN and from WAN 22. These packets typically belong to at least several different flows. The combined bandwidth of the input ports of an ESP 24 is typically greater than the bandwidth of any single output port of ESP 24. Therefore, ESP 24 typically represents a queuing point where packets belonging to various flows may become backlogged while waiting to be transmitted through a port of ESP 24. Backlogs may occur at any output port of ESP 24. While this invention is preferably used to manage the scheduling of packets at all output ports of ESP 24, the invention could be used at only selective output ports of ESP 24.

For example, if the output port which connects ESP 24 to WAN 22 is backlogged, then ESP 24 must determine which packets to send over access link 26, and in which order, to make the best use of the bandwidth available in access link 26 and to provide desired levels of QoS to individual flows. To do this, ESP 24 must be able to classify each packet, as it arrives, according to certain rules. ESP 24 can then identify those packets which are to be

given priority access to link 26. After the packets are classified they can be scheduled for transmission. Typically, all packets in the same flow are classified in the same class.

Incoming packets are sorted into classes according to a policy which includes a set of rules. For each class, the rules specify the properties which a data packet must possess for the data packet to belong to the class. The policy preferably also has attributes for each class establishing QoS levels for that class. Therefore, each class contains rules and attributes, where rules define the identity of the data packet and the attributes define the amount of resource access and usage to route the data packet out of the ESP 24.

As each new packet arrives at ESP 24 from LAN 20 the new packet is classified. Classification involves extracting information intrinsic to a packet such as the source address, destination address, protocol, and so on. Classification may also involve information external to the data packets such as the time of day, day of week, week of the year, special calendar date and the port at which the packet arrives at ESP 24. This information, which comprises a set of parameters for each packet, is used to classify the packet according to a set of rules. The application of rules to a given packet to determine the appropriate class is called "class identification".

If the header 36 and/or external information of a data packet satisfies the rules of a class, then the data packet is identified as the type of service the class represents. For example, consider the rule for a class representing HTTP traffic:

(Source port = 80) or (Destination port = 80)

If the source port in the header 36 in a data packet is equal to 80, then the data packet is classified as HTTP traffic.

Again, a class contains rules and attributes where: (i) rules define the identity of the data packet and (ii) the attributes define the amount of resource access and usage to route the data packet out of the ESP. Since the ESP preferably uses scheduling-based policy management, the classes in a policy will be oriented towards traffic classification. Two broad categories of traffic classification are:

- real time; and
- best effort.

A group of classes represents how the data packets of a set of network services will be ordered out of a termination point, a "termination point" in this context meaning the logical representation of the termination of any transport entity such as a logical output port. This

grouping of classes may be called the "TP policy" since the relation of the classes to one another requires the definition of a policy in respect of that termination point.

If the network service type of each class is completely different and with no overlap (i.e. "orthogonal") to all the others, this would create a flat organization of classes. However, classes can be refined such that classes do not have to be orthogonal to each other. For example, a class specifying a range of source and destination addresses can be refined by a class specifying a narrower range of source and destination addresses. Since classes can be refined, the class organization becomes a tree hierarchy (called a "policy tree") rather than a flat organization.

Figure 4 schematically illustrates a typical policy tree **40**. The root of the tree hierarchy is the TP policy **42** (typically represented by a triangle) and the nodes of the tree are classes **44, 46, 48, 50, 52, 54, 56** (each typically represented by a circle). The leaves (i.e. nodes having no children) of the tree hierarchy are classes that are orthogonal to all the other leaf classes. For example, in Figure 4, the leaf classes **46, 48, 50, 54, 56** are orthogonal to one another. Furthermore, each class in a particular level or layer of the policy tree will be orthogonal to all other classes in that particular level or layer. In Figure 4, classes **44** and **46** in the first layer are orthogonal to each other, classes **48, 50, 52** in the second layer are orthogonal to one another, and classes **54** and **56** in the third layer are orthogonal to each other.

Each of the classes in a typical TP policy contains the name of the class, the type of the service, and the amount of bandwidth it uses. Note that for best effort classes a percentage of the bandwidth is specified, whereas for real time a numerical value is used. This is because real time classes must specify the maximum amount of bandwidth, whereas best effort classes must specify the minimum amount of bandwidth.

Figure 5 schematically illustrates a specific example of a policy tree in practice. It is important to note that a class will always refine its parent's rules and attributes. A class cannot provide rules or attributes that break its parent's set of rules and attributes. Each class in a policy tree can be thought of as containing its own attributes and rules and virtually its parent's attributes and rules. This has a recursive effect such that a class has all the attributes and rules of its parent and its parent's parent all the way up to the root of the policy tree. This notion is called "inheritance". A class inherits all of its parent class's attributes and rules up to but not including the root of the policy tree.

Figure 6 schematically illustrates the inheritance nature of classes in one branch of a policy tree. As illustrated in Figure 6, class B inherits all the attributes and rules of class A. Class C inherits all the attributes and rules of class B, which implies that class C also inherits all the attributes and rules of class A.

The component within the ESP 24 that identifies the data packets as they flow through the ESP 24 is the class identifier. The class identifier may classify packets by using a logical lookup table called the "class lookup table" or "CLT" to identify the type of a data packet and map it to a class ID generated from the logical policy tree. In order to map the class identification of a logical policy tree to the CLT, the logical view of the policy tree is "collapsed" or "compiled" into a flat structure. Only classes that do not have children in the logical view will exist in the compiled view. These classes will contain all the rules required for the CLT. Figure 7 illustrates the mapping between a logical policy tree and a compiled policy tree. In Figure 7, it can be seen that policy tree 60 can logically be compiled into policy tree 62, and that policy tree 62 is the flat-structure logical equivalent of policy tree 60.

Each class in the policy tree represents a specific type of network service and how much network resources will be allocated to its data packets; in other words, each class defines a level of QoS to be assigned to data packets in that class. The data packets are placed into queues or "flows" that correspond to a leaf class in the policy tree. A single flow corresponds to a particular session (such as a TCP/IP session). A flow may also be considered a grouping of packets that belong to the same flow of traffic between two end points in a session. There are a configurable number of flows within each class.

From a logical point of view, there can be a naming convention of classes that map to the physical point of view. For example, a class that has no children may be called a "flow class" because it logically contains the flows where packets are queued. A class that has children is called a "scheduling class" because these classes define how the packets will be scheduled out of the termination point. This naming convention is illustrated in Figure 8, which depicts a class sub-tree where each leaf class is labelled as a flow class and each non-leaf class is labelled as a scheduling class. The difference between flow classes and scheduling classes is also illustrated in Figure 7; it can be seen in Figure 7 that the compiled policy tree 62 that is ultimately used by the class identifier consists solely of flow classes, and that the scheduling classes in the equivalent uncompiled policy tree 60 are merely for directing the data packet to the proper flow class.

Each scheduling class will always have at least two children classes, one of which must be a flow class called the "default sibling class", which holds the flows that match the parent class but none of the other sibling classes. In mathematical terms, the default sibling class is the "logical not" of all the other sibling classes. Every TP policy will have at least one default class, which will be a best effort class that will be equivalent to the conventional method of managing traffic.

The properties of a flow class will be different than the properties of a scheduling class. Specifically, the properties of a flow class will deal with scheduling as well as flow information (for example, how flows are allowed and how many data packets can be queued in a single flow). The properties of a scheduling class deal only with how to schedule data packets out of the termination point (for example, the bandwidth distribution).

Classes are editable when created. After all modifications to a class are completed, the class must be "committed", meaning it is verified and saved. Users can create and store classes and class sub-trees in a "class repository", which can be thought of as a logical storage facility for classes and class sub-trees. Classes may then later be copied from the class repository and placed in a policy tree. The class repository is a useful tool for efficient policy tree creation and modification. It allows developers of graphical user interfaces to create "drag and drop" functionality. Figure 9 schematically illustrates how a leaf Class A is defined and placed in a class repository **64**, and then later copied into a policy tree **66**.

A TP policy within an ESP **24** is defined in the context of the component that sends data packets out, namely, a logical output port. For each ESP **24**, there are typically multiple logical output ports. A single logical output port is associated with a single termination point and TP policy. In turn, a TP policy is defined in terms of a policy tree of classes that are logically associated with a termination point to schedule traffic flowing out through an output port. The following are types of logical output ports that an ESP **24** might handle:

- Ethernet (4 physical ports)
- T1/E1 or voice over IP card (2 physical ports creating 48 voice channels but treated as a single logical output port)
- ATM (1 4xT1 creating 4 physical ports creating up to 256 logical ports)

Since the Ethernet has four logical ports, the voice over IP card has essentially 1 port and the ATM has up to 256 logical ports, there are typically at most 261 TP policies being used in an ESP **24** which is configured in this manner at any particular moment. A voice over IP card is a special case for policy management since it only deals with real time voice traffic.

In this case, the voice over IP logical output port will have only one real time class in the policy tree. The fact that policies are associated only with the output port implies that a policy can be associated with the outgoing flow of data packets from any of:

- LAN to WAN;
- WAN to LAN;
- LAN to LAN; and
- WAN to WAN.

Preferably there is always a default TP policy that is used when no TP policy is associated with a logical output port. The default TP policy contains only the default class, which is a best effort class.

Each class must be verified with respect to all other classes within a TP policy so that there are no conflicts when the TP policy is in-service. Further, each TP policy put into service must be verified against all other TP policies that will be in service at the same time. Consequently, all classes in all TP policies that are put into service must be verified against each other to ensure that there are no conflicts in the CLT. This is required to prevent conflicts when the class identifier component decides which logical output port a data packet should go out of. For example, suppose two classes in two separate TP policies has a single rule:

"source IP address = 111.111.111.111/16"

This would mean that the CLT would have two entries in it with the same rule. Therefore, the class identifier component of the ESP would not know which logical output port the data packets with "source IP address = 111.111.111.111/16" should go out of. From this example, it can be seen that all classes within all TP policies must be verified against each other to confirm that the CLT is free of unresolvable conflict. Furthermore, it must also be confirmed that the information given to the flow identifier and traffic manager components must also be free of conflicts.

Like individual classes, each TP policy can be created, edited, committed (verified and saved), stored in a TP policy repository, and then put into service at a termination point. This is schematically illustrated in Figure 10. In Figure 10, a TP policy "A" is created, edited, committed, and stored in a TP repository 66. Once a TP policy has been committed, it can be put into service by "activating" it. Activating a TP policy means associating it to a termination point. In Figure 10, a TP policy in the TP policy repository 66 is activated by

associating it with a termination point 68, which in this case is an output port 70 of the ESP 24.

At the heart of the ESP 24, has a set of components that process data packets. This set of components is commonly referred to as the "logical packet processing pipeline" (or just "pipeline"), which is schematically illustrated in Figure 11. As shown in Figure 11, an ESP may have six logical components that handle packet processing:

(1)Incoming Packet Manager ("IPM"): This component uses part of the information in a packet's header 36 to determine the next hop.

(2)Route Identifier ("RI"): This component determines which logical output port data packets will go out on.

(3) Class Identifier ("CI"): This component classifies data packets using the TP policy information.

(4) Outgoing Packet Manager ("OPM"): This component physically stores data packets on the ESP 24 for outgoing purposes.

(5) Flow Identifier ("FI"): This component identifies the flow to which a data packet belongs.

(6) Traffic Manager ("TM"): This component uses the flow identifier results and the TP policy to schedule packets out of logical output ports.

In Figure 11, the components affected by policy management are shown in grey. In particular, TP policies affect the following:

- tables used by the IPM (incoming IP packet processing);
- the CLT used by the CI (incoming IP packet processing);
- the flow tables used by the FI (outgoing IP packet processing); and
- the traffic management tables used by the TM (outgoing IP packet processing).

Figure 12 illustrates more clearly how a TP policy is applied to both incoming and outgoing data packets. In the example in Figure 12:

(1) a data packet arrives into the Ethernet Interface Card ("EIC") from the LAN 20;

(2) the CI on the EIC classifies the data packet using the compiled policy tree's identification information;

(3)the IPM on the EIC determines using the TP policy information the logical output port on which the data packet goes out;

(4)the FI on the ATM Interface Card (AIC) determines the flow to which the data packet belongs using the compiled policy tree's property or attribute information;

(5)the TM on the AIC schedules out the data packet using the policy tree property information; and

(6)the data packet leaves the AIC to the WAN 22.

The TP policy information must be distributed to the pipeline components affected by policy management (those shown in grey in Figure 11). In order to understand how to distribute the information to the pipeline components, a high level understanding of the ESP 24 architecture is required. Figure 13 schematically illustrates the organization of these logical pipeline components within the ESP 24. Figure 13 shows that the logical packet processing components are distributed among different cards, including main controller card 74 and interface cards 76, 78. It also shows the propagation of policy information from a policy designer 72 to the particular logical packet processing components within the ESP 24, as follows:.

(1) the TP policy designer 72 creates and commits a TP policy;

(2) the TP policy is put into service;

(3) the TP policy is processed;

(4) the processed TP policy results are distributed to the interface cards 74, 76, 78.

All cards contain a host processor ("HP") where some form of element policy management will be done. The HP on the main controller card 74 manages the logical element policy functionality provided to users. It also processes the logical TP policies to an intermediate form and propagates the results to the HPs on the interface cards 76, 78. Specifically, the HP on the main controller card 74:

(1)compiles the policy tree and generates the logical CLT that the CI requires (since all interface cards require the CLT, the CLT is propagated to all interface cards 76, 78);

(2) using the TP-TP policy association information, generates the required table for IPM for the next hop lookup based on the class ID (since all interface cards requires this table, it is propagated to all interface cards 76, 78); and

(3) using the flow and scheduling class property information, creates a list of flow identifier and scheduling update commands to incrementally change the flow tables and traffic manager tables (since not all the interface cards require the same

information, the HP on the controller card determines which update commands should be propagated to a particular interface card).

TP policy changes must be distributed to the output-processing element on the affected output interface card and to the input-processing elements of all input interface cards. All input interface cards are affected by a TP policy change because the class identifier uses the TP policy information to classify incoming packets into specific service classes. The scheduling engine uses this same policy to map packets into flows and to schedule packets. The HP on the interface cards manages and propagates the processed policy information to the CI, IPM, FI and TM. Specifically, the HP on the interface cards will do the following:

- apply the appropriate table to the IPM and CI;
- implement the appropriate update commands to incrementally change the flow tables managed by the FI; and

•implement the appropriate update commands to incrementally change the traffic management tables managed by the TM.

Proper operation of the ESP 24 requires synchronizing the policy changes to the input and output-processing elements to minimize the impact of policy changes to traffic running through the ESP 24. To accomplish this goal, the ESP 24 supports incremental updates to its policies. Incremental updates to policies imply an inherent latency in completing a policy change. Although allowing abrupt policy change can reduce this inherent latency to near zero time, the traffic impact becomes less predictable. By using incremental policy updates, the ESP 24 balances the need to minimize traffic impacts caused by policy changes with reducing the latency needed to complete a policy change. The changes should preferably be applied to the various pipeline engine tables in a specific order.

When a class is deleted, the affected tables are updated in the following order: (i) classification tables; (ii) flow tables; and (iii) traffic management tables. When a class is added, the affected tables are updated in the following order: (i) traffic management tables; (ii) flow tables; and (iii) classification tables. The order that tables are updated in response to class attribute (such as bandwidth or flow limit) changes depend on the specific attributes being changed. During an incremental change, a TP policy may go through an intermediate transitory period when the TP policy is not valid. The ESP 24 structures its incremental changes to minimize the traffic impacts caused by these transitory TP policies. Figure 14 schematically illustrates how a new TP policy can be put into service over an existing TP policy using incremental changes. Figure 14 shows that to put this particular new TP policy into service, a sequence of incremental changes must be done. The period of time to perform the entire sequence of changes is called the activation latency.

In summary, the basic steps to activate a TP policy are as follows:

(1)create the tables required for the CI and IPM;

(2) differentiate between the classes that are currently in service with the classes that will be put into service to create a list of FI and TM update commands;

(3) distribute and synchronize the deleted classes by applying the tables and the "delete" commands;

(4) distribute and synchronize the added classes by applying the tables and the "add" commands; and

(5) distribute and synchronize the modified classes by applying the tables and the "modify" commands.

As discussed above, a TP policy that is put into service must be verified against all currently in-service TP policies. In addition, a TP policy that will be put into service at a pre-determined time in the future must be verified against all TP policies that will be in-service at the same time. The action of putting a TP policy into service at a pre-determined time in the future is called "scheduling". Scheduling a TP policy is a planning activity that determines what will happen in the future. Typically, scheduling policies can be made easier if there is a reference from which to use. One reference that can be made available is the history of when TP policies went into service. The history of the times when TP policies went into service combined with statistics can provide useful information to determine which TP policies work well together during certain periods of time. For example, statistics may provide information that the traffic flow during Monday evenings were badly congested due to the TP policies, but the traffic flow during Tuesday evenings were fine. A check from the TP policy history could show that there were different TP policies active during Monday evenings than during Tuesday evenings. The Tuesday evening TP policies could then be used on Monday evenings to see if the traffic flow in Mondays improves.

The typical life cycle of a policy is as follows:

(1) one or more classes are created according to the expected type of network services routed through the ESP 24;

(2) one or more TP policies are created using new or existing classes and/or class sub-trees;

(3) one or more TP policies are manually put into service;

(4) another TP policy may be put into service manually or automatically (through a scheduling mechanism); and

(5) a class or TP policy may be deleted only if it is editable and not associated with the in-service TP policy.

Preferred implementations of the invention may include a computer system programmed to execute a method of the invention. The invention may also be provided in the form of a program product. The program product may comprise any medium which carries a set of computer-readable signals corresponding to instructions which, when run on a computer, cause the computer to execute a method

of the invention. The program product may be distributed in any of a wide variety of forms. The program product may comprise, for example, physical media such as floppy diskettes, CD ROMs, DVDs, hard disk drives, flash RAM or the like or transmission-type media such as digital or analog communication links.

The following describes a specific policy change characterization method and apparatus according to the invention.

GLOSSARY

Classification A set of rules that uniquely identify a set of packets.

ESP Enterprise Service Point- packet forwarding and QoS enforcement device.

QoS Quality of service.

QoS Requirements The quality to give the classified packets.

Class A class is a set of classification rules that identify packets that belong to the class, QoS requirements, and other properties that specify how the packets will be forwarded out of the ESP.

Rule Expression A rule that contains a set of orthogonal rule type expressions logically ANDed together. Orthogonal rule type expressions means that the rule type of each rule type expression shall not exist more than once in the rule expression.

Policy A policy is a tree hierarchy of classes.

1 Introduction

An ESP according to a currently preferred embodiment of the invention uses policies to control how packets are forwarded out each of its output logical ports. Each output logical port has its own policy. A policy consists of a tree of classes.

Each class identifies a subset of packets passing through the ESP and specifies the treatment to be provided to those packets. Treatment may include one or more of QoS (e.g. bandwidth, delay, jitter, reliability), security (e.g. encryption), admission control (i.e. how many data connections will be allowed), and other types of packet forwarding treatment.

A class identifies a subset of packets using one or more classification rules. A classification rule consists of one or more rule terms. Each rule term consists of two parts: the identity of a data item and a set of constant values. A data item may be a field in a received packet. A data item may be a value from the environment in which the packet was received. The set of constant values can contain individual values, ranges of constant values, and, in the case of IP addresses, IP subnets expressed in CIDR notation.

The data items supported by an may include, for example:

- Source IP address (received packet's IP header)
- Destination IP address (received packet's IP header)
- TCP or UDP source port (received packet's TCP or UDP header)
- TCP or UDP destination port (received packet's TCP or UDP header)
- ESP input logical port (environment)
- Type Of Service (TOS) byte (aka Differentiated Services (DS) byte) (received packet's IP header)
- Protocol (received packet's IP header)
- TCP Ack Flag (received packet's TCP header)

Additional data items may also be supported. All techniques described in this document are applicable to classification schemes supporting a different set of data items.

Each type of data item may be termed a classification dimension. A rule term is allowed to be missing from a classification rule for any of the classification dimensions. A missing rule term is equivalent to a rule term that specifies the full legal range of values for the data item i.e. it specifies a wild card dimension for the class.

When a packet is received, classification rules are evaluated to classify the packet. If the value of the data item matches any of the constant values specified in a rule term, the rule term is considered to be satisfied. If all of the rule terms of a classification rule are satisfied, the classification rule is satisfied. If a rule is satisfied, the packet is considered to belong to the class to which the rule corresponds.

It is usually an error for two or more rules from different classes to be satisfied by a single packet. Policy validation prevents this from occurring except in certain restricted circumstances.

As mentioned above a policy consists of a tree of classes. Packet classification takes place only in the lowest (leaf) classes. Packets can be viewed as entering the policy tree at the leaf class level. Packets percolate upwards through the tree until they reach the root of the tree. The root of the tree is associated with the data link attached to the output logical port. Packets leave the tree by being transmitted on the data link.

Each class in the tree can specify treatment of packets. For example, each class will generally specify bandwidth. The bandwidth of each parent class must be equal to or greater than the sum of the bandwidth of all child classes. The root of the tree corresponds to the bandwidth of the data link. This allows the data link's bandwidth to be segregated amongst classes of packets.

Although packet classification only takes place at the leaf class level, classification rules can be specified in higher classes. This is a convenience feature that provides a shorthand way of specifying common rules at higher levels of the tree.

If both a child class and its parent class contain rules, the rules in the child class must match a subset of the packets that the rules in the parent class match. In other words, the child class rules must restrict or limit the parent class rules.

The actual classification rules used in a leaf class are generated via rule compilation. Starting at the top of the class tree, rules are merged downwards to the leaf classes. The resulting merged rules are transformed into data structures that control the packet processing pipeline.

The packet processing pipeline will generally have packets queued for transmission on a data link. There are queues and waiting packets associated with each policy leaf class. New policies may be activated while the ESP is processing packets. When a new policy is activated, the new policy's class tree structure, classification rules, and packet treatment may be different from those of an existing policy. To put the new policy into effect the ESP may need to delete queues, add queues, reassign queues to various leaf classes during the transition from the old policy to the new policy.

Given the disruption that can occur, it is highly desirable to minimize the amount of change in the packet processing pipeline. Since policy changes normally only involve one or two classes out of potentially many classes, the inventor has determined that there is an excellent opportunity to minimize the amount of disruption if the unchanged classes can be identified.

As it turns out, changes in packet treatment can be accommodated without much disruption. It is classification rule changes and class tree structure changes that cause the most disruption in the packet processing pipeline.

This invention provides a strategy for determining the difference between two policies. The differentiation process is used to determine the minimum number of changes that are required to replace an old policy with a new policy.

2 Policy Overview

For the purpose of this document, a class can be considered to comprise the following components:

- Classification Rules
- QoS Requirements

2.1 Classification

Classification rules are described above.

For the purpose of the techniques described in this document, it is useful to introduce the concept of a classification mask. A classification mask is bit mask that specifies which dimensions are specified by the terms of a classification rule or rules. The mask may be, for example, 8 bits in length covering the 8 dimensions of classification (source IP address, destination IP address, source TCP/UDP port, destination TCP/UDP port, protocol, incoming logical port, TOS/DS byte, and TCP Ack flag).

The following is the mask:

Bit 0: source IP address
Bit 1: destination IP address
Bit 2: source TCP/UDP port
Bit 3: destination TCP/UDP port
Bit 4: incoming logical port
Bit 5: TOS/DS byte
Bit 6: protocol
Bit 7: TCP Ack flag

If bit 0 in the mask is set to 1, there is a rule term for source IP address in the classification rules, otherwise, if bit 0 in the mask is set to 0, there is no source IP address rule term.

The following is a diagram showing the classification bit mask:

Ack	protocol	TOS/DS byte	input log. port	dst T/U port	src T/U port	dst IP address	src IP address
7	6	5	4	3	2	1	0

Figure 15: Classification Mask

For example, if the mask is 19, the binary version of this is 10011, bits 0, 1 and 4 are set. This means that the classification rule:

- specifies source IP address, destination IP address and incoming logical port
- does not specify source TCP/UDP port, destination TCP/UDP port, TOS/DS byte, protocol, or TCP Ack flag i.e. any value is acceptable

The ESP performs longest prefix matching for the two IP address dimensions. For other dimensions, a more specific range or values fully contained in a less specific range is given preference.

Classification Rule Compilation

The ESP uses a classification engine in the packet processing pipeline to classify packets. The classification engine compares the packet header and environment data items with rules associated with leaf classes. To deploy a new policy, it is necessary to compile the classification rules into a form that the classification engine can use. This involves the merging of rules from parent classes down into child classes unless a child class overrides a parent class rule with a more specific rule.

Figure 16 is a diagram showing a very simple form of rule compilation.

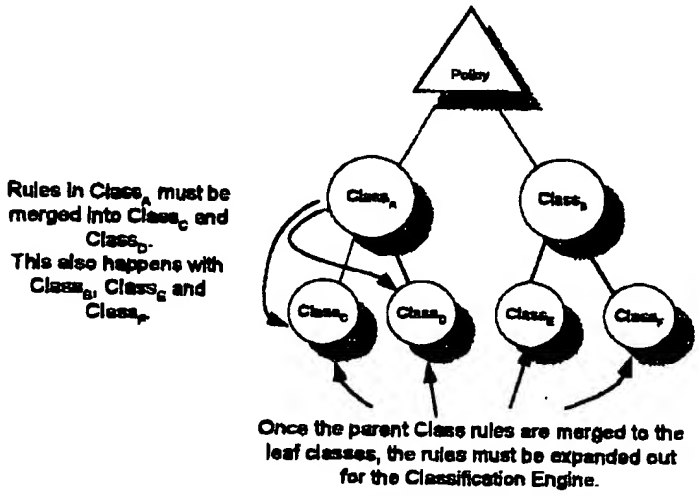


Figure 16: Class Rule Compilation (Basics)

For example, suppose there were two trees that looked like the one in Figure 16. In the first tree, suppose:

$Tree_1$, $Class_A$ rule: source IP = 1.0.0.0/24

$Tree_1$, $Class_C$ rule: destination IP = 2.0.0.0/24

$Tree_1$, $Class_C$ compiled rule: source IP = 1.0.0.0/24, destination IP = 2.0.0.0/24

Now suppose the second tree's had:

$Tree_2$, $Class_A$ rule: destination IP = 2.0.0.0/24

$Tree_2$, $Class_C$ rule: source IP = 1.0.0.0/24

$Tree_2$, $Class_C$ compiled rule: source IP = 1.0.0.0/24, destination IP = 2.0.0.0/24

Notice that both the first and second tree's $Class_C$ have the same compiled rule, but the rule in $Class_A$ and $Class_C$ in both trees were different. The classification engine only cares about the compiled rule for each leaf class. Therefore, the classification rules of $Class_C$ in both trees are the same.

2.2 Rules for Compilation

Policy management requires each child's rules to be more restricted than its parent's rules. If a dimension of a child's rule is not a subset of the same dimension of its parent's rule, then an error has occurred. Child rules always take precedent over parent rules. As a result, the child rule is always used when parent and child rules are merged. For example:

Parent Rule:	Source IP=1.0.0.0/24, 2.0.0.0/24
Child Rule:	Source IP= 1.0.0.2/32
Merged Rule At Child:	Source IP= 1.0.0.2/32

The parent rule in the example means that packets can match a source IP address of 1.0.0.0/24 or 2.0.0.0/24. The child rules state that packets must match a source IP address of 1.0.0.2/32. When the merge of parent with child occurs, all the child rules prevail since the merge must be the largest subset between the two, which will always be all the child's rules.

Note that if a value in a rule within a child is not a subnet of the parent's values, then an error has occurred and should be reported back to the user. For example:

Parent Rule:	Source IP=1.0.0.0/24, 2.0.0.0/24
Child Rule:	Source IP= 3.0.0.2/32

Merged Rule At Child: Source IP= *<empty - error>*

In this example, the source IP address of the child is not a subset of any of the parent values resulting in an error.

If a parent rule is empty, it means all possible values are acceptable. If a child has rules in a dimension and the parent does not, then any value a child has is valid. For example:

Parent Rule:	Source IP=
Child Rule:	Source IP= 1.0.0.2/32
Merged Rule At Child:	Source IP= 1.0.0.2/32

Using this strategy reduces the parent classes to the child leaf classes by processing only similar dimension types first. Once all the dimension types are processed, then the expansion of the rules can be done.

2.3 Class Rule Compilation Notation

The following shorthand notation is used in subsequent examples:

Shorthand For Dimension Types

SIP=Source IP Subnet Value

DIP=Destination IP Subnet Value

SP=Source port range Value

DP=Destination port range Value

IP=Incoming Port Identifier Value

TOS=TOS/DS byte Value

P=Protocol Value

TCP=TCP Session Creation Flag Value

So SIP_1 could mean 1.0.0.0/24 and SIP_2 could mean 2.0.0.0/24.

Shorthand For Rules

The table shows the class levels in rows. The columns are the dimensions. The values in each cell is the subscript value meaning a unique value of that dimension type:

	SIP	DIP	SP	DP	IP	TOS	P	TCP
Class Rule at Level 1:	1,2,3	1,2	1	1,2				
Class Rule at Level 2:	4,5		4,5		1			

The above example table implies that there are two levels in the policy. Each row represents the rules in a single class. In this case the rules are:

Class Rule at Level 1: $(SIP_1 \mid SIP_2 \mid SIP_3)$ & $(DIP_1 \mid DIP_2)$ & (SP_1) & $(DP_1 \mid DP_2)$

Class Rule at Level 2: $(SIP_4 \mid SIP_5)$ & $(SP_4 \mid SP_5)$ & (IP_1)

If:
SIP_1 = 1.0.0.0/24
SIP_2 = 2.0.0.0/24
SIP_3 = 3.0.0.0/24
DIP_1 = 4.0.0.0/24
DIP_2 = 5.0.0.0/24
SP_1 = 10-100
DP_1 = 10-100
DP_2 = 200-300
Then

Class Rule at Level 1:
(SIP=1.0.0.0/24 | SIP=2.0.0.0/24 | SIP=3.0.0.0/24) & (DIP=4.0.0.0/24 | DIP=5.0.0.0/24) & (SP=10-100) & (DP=10-100 | DP=200-300)

If Figure 17 is the diagram for this rule compilation example:

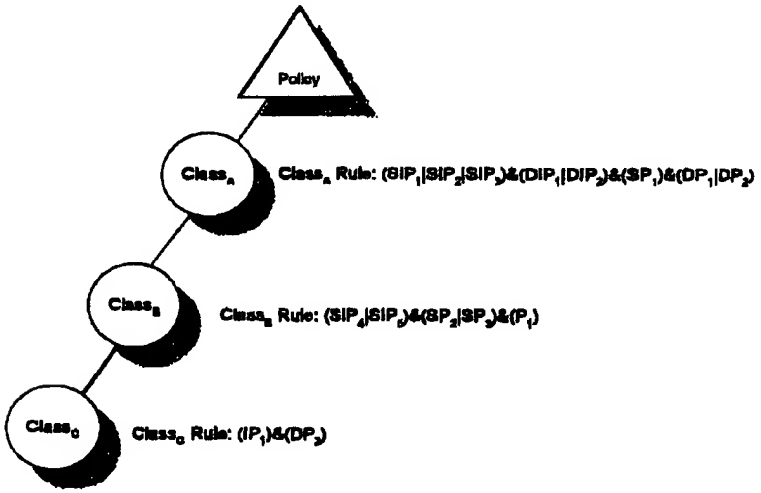


Figure 17: Example Path In Policy To Compile

The table to compile this would look like the following:

	IP	IP	P	P	P		OS	CP
$Class_A$ Rule	,2,3	,2		,2				
$Class_B$ Rule	,5		,3					
$Class_C$ Rule								

Table 1: Shorthand Compilation Table

2.4 Brute Force Rule Compilation Method

The brute force mechanism performs the compilation process using the following steps starting at the root class:

- Expand the parent rules into a set of basic rules.
- Expand the child rules into a set of basic rules.
- Combine (logical AND) the parent basic rules and child basic rules.
- Eliminate more general terms in favour of more specific terms.
- Repeat this process downwards through the class tree until the child class is a leaf class.

This process requires more time than many users would be willing to tolerate.

For example, if the following was given:

	IP	IP	P	P	P		OS	CP
$Class_A$ Rule	,2	,2						
$Class_B$ Rule								

Table 2: Brute Force Compilation Example

Then the compilation would be as follows:

Expand the parent rules into a set of basic rules:

$(SIP_1 \& DIP_1 \& SP_1 \& DP_1) \mid (SIP_1 \& DIP_2 \& SP_1 \& DP_1) \mid (SIP_2 \& DIP_1 \& SP_1 \& DP_1) \mid (SIP_2 \& DIP_2 \& SP_1 \& DP_1)$

Next expand the child rules into a set of basic rules:

$(SIP_3 \& SP_2 \& P_1)$

Logically AND the parent and child basic rules:

$(SIP_1 \& DIP_1 \& SP_1 \& DP_1 \& SIP_3 \& SP_2 \& P_1) | (SIP_1 \& DIP_2 \& SP_1 \& DP_1 \& SIP_3 \& SP_2 \& P_1) | (SIP_2 \& DIP_1 \& SP_1 \& DP_1 \& SIP_3 \& SP_2 \& P_1) | (SIP_2 \& DIP_2 \& SP_1 \& DP_1 \& SIP_3 \& SP_2 \& P_1)$

Eliminate more general terms in favour of more specific terms . In this example, assume that SIP_3 is not a subset of SIP_2 but is a subset of SIP_1 and SP_2 is a subset of SP_1:

$(DIP_1 \& DP_1 \& SIP_3 \& SP_2 \& P_1) | (DIP_2 \& DP_1 \& SIP_3 \& SP_2 \& P_1)$

If SIP_3 were not a subset of SIP_1 or SIP_2, then the set would be empty.

Notice that when the child rules were compiled in with the parent rules, whenever there was a specified child dimension, the child dimension essentially eliminated the parent dimension values. This will always be the case and is the basis of the next compilation method.

2.5 Improved Rule Compilation Method

A better technique for compiling rules takes advantage of rule elimination (shown in a previous section).

The technique processes a pair of parent-child rules at a time. Specifically, compile the root and its child to get a new set of rules. Then compile the resulting rules with the next child's rules. Note that the rules are not expanded out to their basic rules until the leaf child has been reached.

When compiling parent and child rules together, terms for each dimension are processed separately. Logically AND the terms for each dimension together to create a new rule. When doing this, the only check that needs to be done is to ensure each child rule term is a subset of at least one parent rule term of the same dimension. If this check succeeds, then the new rule generated will simply contain all the child rule terms.

Consider the example in the brute force section:

	IP	IP	P	P	P		OS	CP
$Class_A$ Rule	,2	,2						

$Class_B$ Rule								

Table 3: Rule Compilation Example

Then the following would be done:

	IP	IP	P	P	P		OS	CP
$Class_A$ Rule	,2	,2						
$Class_B$ Rule								
New Rule		,2						

Table 4: New Rule Generation Example

Notice that if the child rule terms are valid (meaning that all the child rule terms are a subset of at least one of the parent rule terms), then the child rule terms are always in the new rule expression, never the parent rule terms.

If a child rule term is not a subset of any of its parent rule terms, then an error has occurred and should be reported to the user.

When the new rule at the child leaf class is finally created, then it can be expanded to its basic rules:

$(SIP_3 \& DIP_1 \& SP_2 \& DP_1 \& P_1) \mid (SIP_3 \& DIP_2 \& SP_2 \& DP_1 \& P_1)$

Notice that this is the same result as the brute force method, but the technique was much simpler.

If there were a class under $Class_B$, then the rules for the new child class would be combined with the New Rule generated by combining $Class_A$ and $Class_B$ before expanding to the basic rules.

3 Detection of Possible Equivalent Leaf Classes

Once the rules are compiled in both policy trees, leaf classes are analyzed to detect possible equivalent leaf classes.

It is inefficient to simply perform a pairwise comparison of classes in the old and new policy trees to see if their compiled classification rules are equivalent. If each tree has approximately N classes, then each of N classes in the old policy must be compared with up to N classes in the new policy. On average it will be necessary to examine N/2 classes in the new policy before a match is found. If classes in the new policy are marked as being part of a match then it will be necessary to examine N/4 classes in the new policy on average. This results in a total of $N^2/4$ class comparisons. This assumes of course that the new policy is only a slight modification of the old policy. If not, the absolute worse case of N^2 class comparisons may have to be performed only to find that there are no matches.

Instead it can be preferably to use a method whereby one only needs to completely process the classes in one of the trees. The logical choice would be the old policy tree since its classes are the ones that can be carried forward unchanged into the new policy. As each class in the old policy tree is processed it would be preferable to have a method that would compare the class to only log N or fewer classes in the new policy tree.

3.1 Log N Data Structure Method

One method for doing this is to define a comparison function that returns a result of less than, equals, or greater than when it is provided with the classification rules of two classes to compare. The comparison function is used as the basis for inserting all of the classes from the new policy tree into a suitable data structure. An appropriate data structure would be a binary tree, skip list, or the like that supports O(log N) insert and search performance. The result is that all of the classes from the new policy tree are sorted in the order dictated by the chosen comparison function.

Proceeding in an iterative manner, each class from the old policy is compared with the classes in the data structure in order to identify a class from the new policy with equivalent classification rules. Because the data structure supports

O(log N) searching, identification of equivalent leaf classes should be accomplished with performance of O(N log N).

3.1.1 Rule Pre-Processing

Determination of classification rule equality will be eased if the classification rules of each class are pre-processed to maximize correspondence and consistency.

Rule terms should be simplified as much as possible. For example, if a rule contained two rule terms for a single dimension, they should be coalesced into a single term. If a rule term contains multiple constant values/ranges, adjacent or overlapping values should be merged into a single constant range value.

If a class has multiple rules, some basis should be chosen for sorting the rules. This allows corresponding rules of two classes to be easily compared.

3.1.2 Comparison Functions

The chosen comparison function must be able to accurately determine that the classification rules of two classes are equal. Other than equality, an arbitrary basis can be used to determine that the rules of one class are less than or greater than the rules of the other class.

One possible comparison function for the rules of two classes A and B might be based on the following logic:

1. Compare the number of rules each class has. If the number of rules is identical, continue with step 2. If class A has fewer rules, return less than as the value of the function. Otherwise return greater than.
2. Compare the classification masks of corresponding rules. If each pair of rules has identical masks, continue with step 3. For the first mismatching pair of rules, if the binary value of mask A is less than the binary value of mask B, return less than as the value of the function. Otherwise return greater than.
3. Compare the number of constant values/ranges in the source IP address terms of corresponding rules. If each pair of rules has the same number of constant values/ranges, continue with step 4. For the first mismatching pair of rules, if rule A has fewer constant values/ranges, return less than as the value of the function. Otherwise return greater than.

4. Compare the constant values/ranges in the source IP address terms of corresponding rules. If each pair of rules has the same constant values/ranges, continue with step 5. For the first mismatching constant value/range in the first mismatching pair of rules, if the rule A constant value/range has a lesser value (constant value), lesser starting value (constant range), or lesser final value (constant range), return less than as the value of the function. Otherwise return greater than.

5. Compare the number of constant values/ranges in the destination IP address terms of corresponding rules. If each pair of rules has the same number of constant values/ranges, continue with step 6. For the first mismatching pair of rules, if rule A has fewer constant values/ranges, return less than as the value of the function. Otherwise return greater than.

6. Compare the constant values/ranges in the destination IP address terms of corresponding rules. If each pair of rules has the same constant values/ranges, continue with step 7. For the first mismatching constant value/range in the first mismatching pair of rules, if the rule A constant value/range has a lesser value (constant value), lesser starting value (constant range), or lesser final value (constant range), return less than as the value of the function. Otherwise return greater than.

7. Compare the number of constant values/ranges in the source TCP/UDP port terms of corresponding rules. If each pair of rules has the same number of constant values/ranges, continue with step 8. For the first mismatching pair of rules, if rule A has fewer constant values/ranges, return less than as the value of the function. Otherwise return greater than.

8. Compare the constant values/ranges in the source TCP/UDP port terms of corresponding rules. If each pair of rules has the same constant values/ranges, continue with step 9. For the first mismatching constant value/range in the first mismatching pair of rules, if the rule A constant value/range has a lesser value (constant value), lesser starting value (constant range), or lesser final value (constant range), return less than as the value of the function. Otherwise return greater than.

9. Compare the number of constant values/ranges in the destination TCP/UDP port terms of corresponding rules. If each pair of rules has the same number of constant values/ranges, continue with step 10. For the first mismatching pair of

rules, if rule A has fewer constant values/ranges, return less than as the value of the function. Otherwise return greater than.

10. Compare the constant values/ranges in the destination TCP/UDP port terms of corresponding rules. If each pair of rules has the same constant values/ranges, continue with step 11. For the first mismatching constant value/range in the first mismatching pair of rules, if the rule A constant value/range has a lesser value (constant value), lesser starting value (constant range), or lesser final value (constant range), return less than as the value of the function. Otherwise return greater than.

11. Compare the number of constant values/ranges in the protocol terms of corresponding rules. If each pair of rules has the same number of constant values/ranges, continue with step 12. For the first mismatching pair of rules, if rule A has fewer constant values/ranges, return less than as the value of the function. Otherwise return greater than.

12. Compare the constant values/ranges in the protocol terms of corresponding rules. If each pair of rules has the same constant values/ranges, continue with step 13. For the first mismatching constant value/range in the first mismatching pair of rules, if the rule A constant value/range has a lesser value (constant value), lesser starting value (constant range), or lesser final value (constant range), return less than as the value of the function. Otherwise return greater than.

13. Compare the number of constant values/ranges in the TOS/DS byte terms of corresponding rules. If each pair of rules has the same number of constant values/ranges, continue with step 14. For the first mismatching pair of rules, if rule A has fewer constant values/ranges, return less than as the value of the function. Otherwise return greater than.

14. Compare the constant values/ranges in the TOS/DS byte terms of corresponding rules. If each pair of rules has the same constant values/ranges, continue with step 15. For the first mismatching constant value/range in the first mismatching pair of rules, if the rule A constant value/range has a lesser value (constant value), lesser starting value (constant range), or lesser final value (constant range), return less than as the value of the function. Otherwise return greater than.

15. Compare the constant values in the TCP Ack flag terms of corresponding rules. If each pair of rules has the same constant values, continue with step 16. For

the first mismatching constant value in the first mismatching pair of rules, if the rule A constant value has a lesser value, return less than as the value of the function. Otherwise return greater than.

16. Compare the number of constant values/ranges in the input logical port terms of corresponding rules. If each pair of rules has the same number of constant values/ranges, continue with step 17. For the first mismatching pair of rules, if rule A has fewer constant values/ranges, return less than as the value of the function. Otherwise return greater than.

17. Compare the constant values/ranges in the input logical port terms of corresponding rules. If each pair of rules has the same constant values/ranges, continue with step 18. For the first mismatching constant value/range in the first mismatching pair of rules, if the rule A constant value/range has a lesser value (constant value), lesser starting value (constant range), or lesser final value (constant range), return less than as the value of the function. Otherwise return greater than.

18. Return equals as the value of function.

3.2 Hash Table Method

An alternative method for identifying possible equivalent leaf class pairs uses a hash table. This method can provide better performance.

A hash function is chosen that generates a hash index based on many of the parameters used in the comparison function described above. The hash index is used to index into a hash table that is several times larger than the expected number of classes. If the chosen hash function has good uniformity, there will be very few collisions.

The classes from the new policy are inserted into the hash table. Iterating over the classes in the old policy, the hash index is calculated. If the hash index of a class in the old policy tree corresponds to the hash index of a class in the new policy tree, a detailed comparison of the classification rules of the two classes is performed. A variant of the above comparison function that only tests for equality could be used.

Use of a hash table method should provide O(N) performance.

The chosen hash function should keep in mind that real-life classification rules are more likely to include terms for the source IP address,

destination IP address, source TCP/UDP port, destination TCP/UDP port, and protocol dimensions than other dimensions. Clustering of source and destination IP addresses will be seen. Clustering of quantities of constant values/ranges will also be seen.

4 Policy Differentiation

The ESP classification engine is not concerned with the structure of parent classes above the leaf classes. It is only concerned with the compiled rules for each leaf class.

However, the ESP packet scheduler cares about the structure of classes, because its packet handling mirrors the tree structure. To generate the data structures that will control the packet scheduler, it is strongly preferred that we find the minimum set of changes that will transform the old data structures into the new structures. Class adds and deletes cause the most disruption in the packet processing pipeline whereas class changes and class equivalencies cause little or no disruption to the running packet pipeline.

If the packet treatment of a class is changed, it can be handled by a class change, because this only requires that parameters in the existing data structure be modified.

If the classification rules of a class change, the class in the old policy must be completely deleted and the revised class added to the new tree. This is because packets queued in the old class may not satisfy the new classification rules. Classification rule changes only affect the packet scheduler for leaf classes, since it is not aware of any rules existing for non-leaf classes.

The focus of policy differentiation must be to identify incompatible changes in leaf class classification rules. As will be seen in the next section, structural considerations such as tree depth also come into play.

4.1 Parent Lineage Rules

The packet scheduler's packet processing data structures mirror the structure of the policy tree. The following rules concerning parent lineage must be satisfied if two leaf classes are to be considered equivalent:

- the number of classes between leaf classes and the root must be identical
- if a pair of leaf classes in the old policy is to be considered equivalent to a pair of leaf classes in the new policy, and either pair has the same parent class, the other pair must also have the same parent class

As an example of applying these rules consider Figure 18:

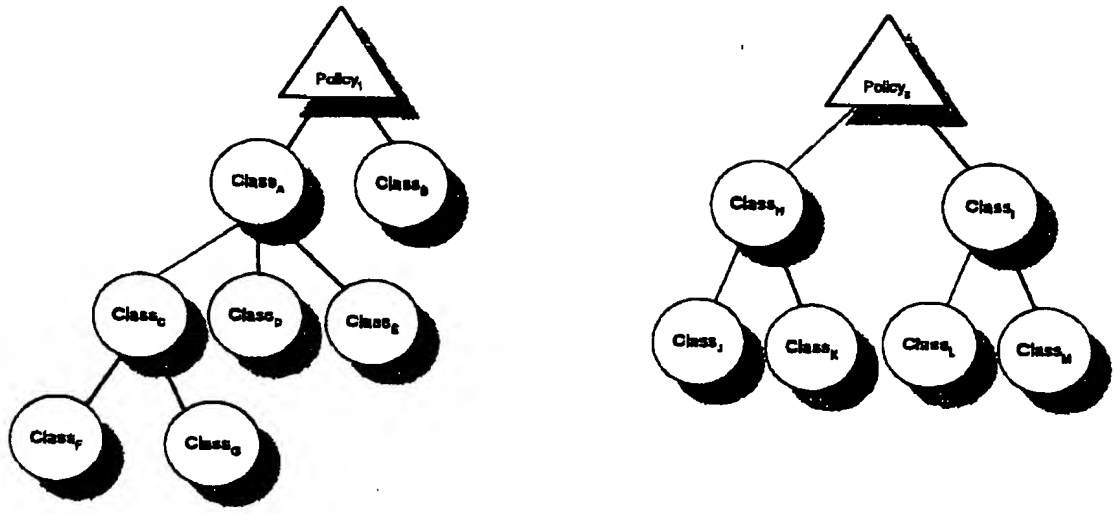


Figure 18: Example Parent Class Lineage

Assume the following:

- $Class_F$ and $Class_J$ have the same set of compiled rules ($rules_1$)
- $Class_D$ and $Class_K$ have the same set of compiled rules ($rules_2$)
- $Class_E$ and $Class_L$ have the same set of compiled rules ($rules_3$)

Notice the following parent class lineage:

$Class_F$: $Class_F \rightarrow Class_C \rightarrow Class_A$

$Class_D$: $Class_D \rightarrow Class_A$

$Class_E$: $Class_E \rightarrow Class_A$

$Class_J$: $Class_J \rightarrow Class_H$

$Class_K$: $Class_K \rightarrow Class_H$

$Class_L$: $Class_L \rightarrow Class_I$

Applying the above rules:

- $Class_F$ and $Class_J$ cannot be the same since $Class_F$ has two parents to the root whereas $Class_J$ has one
- $Class_D$ and $Class_K$ can be considered the same since they both have one parent to the root.
- $Class_E$ and $Class_L$ cannot be considered the same even though both only have one parent to the root. This is because:

$Class_D$ and $Class_K$ have already been designated to be the same

$Class_D$ and $Class_E$ have the same parent

$Class_K$ and $Class_L$ do not have the same parent.

For $Class_E$ and $Class_L$ to be the same, $Class_L$ must have be a child of $Class_H$.

Note that if $Class_E$ and $Class_L$ were considered to be the same, then $Class_D$ and $Class_K$ could not be considered the same for the same reason.

4.2 Determining Parent Lineage Equality

Only those leaf classes that have the same compiled classification rules need to be checked for parent lineage equality.

Here are some further observations about parent lineage equality:

- If two leaf classes are to be considered equivalent, their complete parent lineage must be considered equivalent.
- In situations where it is ambiguous as to which parent classes are to be considered equivalent, the ambiguity should be resolved in favour of the parent that maximizes the number of equivalent leaf classes.

An example of the second observation can be considered with reference to Figure 19.

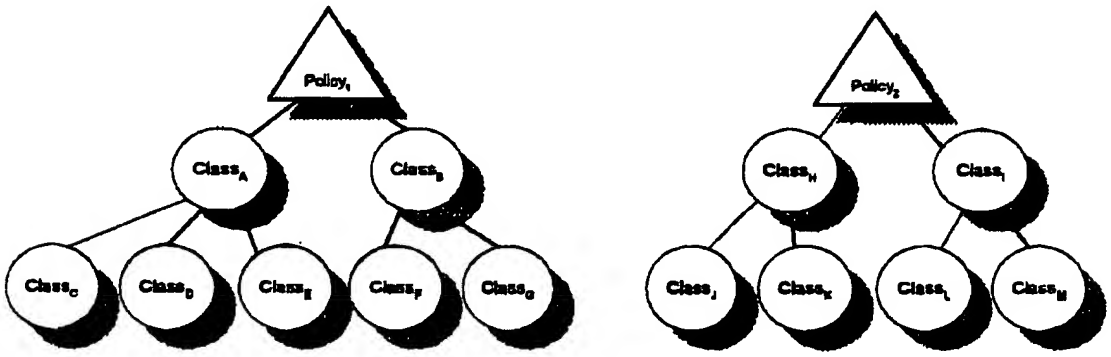


Figure 19: Parent Class Lineage Determination

The structure of the two policies is as follows:

- $Class_C$, $Class_D$ and $Class_E$ are under the same $Class_A$
- $Class_F$ and $Class_G$ are under the same $Class_B$
- $Class_J$ and $Class_K$ and under the same $Class_H$
- $Class_L$ and $Class_M$ are under the same $Class_I$

Assume the following:

- $Class_C$ has the same set of compiled rules as $Class_J$
- $Class_D$ has the same set of compiled rules as $Class_K$
- $Class_E$ has the same set of compiled rules as $Class_L$
- $Class_F$ has the same set of compiled rules as $Class_M$

Consider the possibility of making a final determination that $Class_E$ and $Class_L$ are equivalent. This would necessitate that $Class_A$ and $Class_I$ be considered equivalent. This would prevent the $Class_C$ - $Class_J$ and $Class_D$ - $Class_K$ equivalencies, because those equivalencies require that $Class_A$ and $Class_H$ be considered equivalent. Given our desire for minimal change, this ambiguity would be resolved by preferring the $Class_C$ - $Class_J$ and $Class_D$ - $Class_K$ equivalencies.

4.3 Equivalent Parent Lineage Determination Technique

To find equivalent parent lineage, iterate downwards through the levels of the two policy trees, starting at the root, and find the most matching sets of leaf classes under the classes at the given level.

A level iteration discards leaf classes that do not have the same parent lineage at that level, but will keep the best matching leaf classes.

This is done by:

- Before iterating, number each of the classes in both trees.
- Find the pairs of leaf classes (a pair consists of a leaf class from one policy tree and a leaf class from the other policy tree) that have the same set of compiled rules (see 2.5).
- Iterate downwards through the levels of classes in both policy trees (note that there is no need to iterate over the leaf class level, since it will not be a parent of any classes)
    - For each node at the given level, assign to the node all descendant leaf classes that are equivalent to leaf classes in the other policy tree
    - Iteratively find pairs of nodes, one in each tree, at the given level that share the greatest number of equivalent leaf class pairs. Consider this pair of nodes to be equivalent and remove it and their assigned leaf classes from consideration. Continue iterating until there are no more nodes with assigned leaf classes.

- For any leaf class that has been assigned to one of the nodes, and the equivalent leaf class has not been assigned to the other node, drop that equivalent leaf class pair from future consideration as an equivalent leaf class pair.

4.3.1 Class Numbering

Consider the two policies shown in Figure 20.

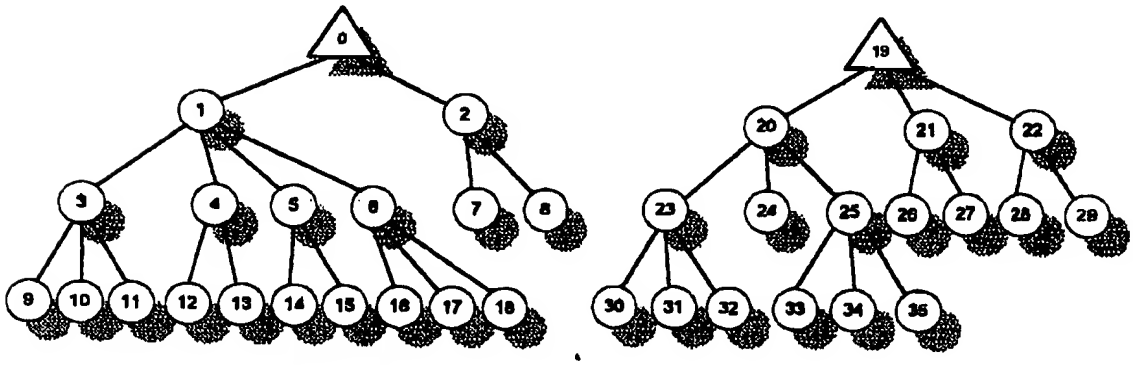


Figure 20: Parent Class Lineage Technique Example

Figure 20 has the classes and policies numbered as specified above.

4.3.2 Finding Matching Class Pairs

The next step is the find the pairs of leaf classes that have the same set of compiled rules. Assume the following for this step:

Set of compiled rules in $Class_{11}$ = Set of compiled rules in $Class_{32}$

Set of compiled rules in $Class_{9}$ = Set of compiled rules in $Class_{33}$

Set of compiled rules in $Class_{10}$ = Set of compiled rules in $Class_{35}$

Set of compiled rules in $Class_{12}$ = Set of compiled rules in $Class_{24}$

Set of compiled rules in $Class_{7}$ = Set of compiled rules in $Class_{28}$

Set of compiled rules in $Class_{8}$ = Set of compiled rules in $Class_{29}$

So the equivalent leaf classes are:

11, 32

9, 33

10, 35

12, 24

7, 28

8, 29

4.3.3 Level Iteration

The next step is to iterate over the levels. Specifically:

- The root level would consist of finding all the leaf classes under $root_0$ and $root_{19}$.
- The next level would be to find the leaf classes under $Class_1$, $Class_2$, $Class_{20}$, $Class_{21}$ and $Class_{22}$.
- The last level would be to find the leaf classes under $Class_3$, $Class_4$ $Class_5$, $Class_6$, $Class_{23}$ and $Class_{25}$.

Consider the level grouping of Table 5:

	$Root_0$	$Root_{19}$
Root Level	7, 8, 9, 10, 11, 12	24, 28, 29, 32, 33, 35
2nd Level	7, 8 9, 10, 11, 12	24, 32, 33, 35 28, 29
3rd Level	9, 10, 11 12	32 33, 35

Table 5: Equivalent Leaf Class Groups

What this table indicates the groups of class assignments to a common parent. Specifically:

- Classes 7, 8, 9, 10, 11, 12 have a common parent at the root level ($Root_0$)
- Classes 7, 8 have a common parent at the 2nd level ($Class_2$)
- Classes 9, 10, 11, 12 have a common parent at the 2nd level ($Class_1$)
- Classes 9, 10, 11 have a common parent at the 3rd level ($Class_3$)
- Class 12 has a parent at the 3rd level ($Class_4$)
- Classes 24, 28, 29, 32, 33, 35 have a common parent at the root level ($Root_{19}$)
- Classes 24, 32, 33, 35 have a common parent at the 2nd level ($Class_{20}$)
- Classes 28, 29 have a common parent at the 2nd level ($Class_{22}$)
- Class 32 has a parent at the 3rd level ($Class_{23}$)
- Classes 33, 35 have a common parent at the 3rd level ($Class_{25}$)

4.3.3.1 Matching Nodes at Each Level of Iteration

At each of the levels, the pairs of nodes sharing the most equivalent leaf class pairs are found. The equivalent leaf class nodes corresponding to unshared leaf classes assigned to the nodes are discarded.

For example, the following leaf classes are assigned to the two root nodes:

7, 8, 9, 10, 11, 12 to $Root_0$

24, 28, 29, 32, 33, 35 to $Root_{19}$

Each of the six leaf classes on the left is equivalent to one of the six leaf classes on the right. For example, $Class_{11}$ has the same set of compiled rules as $Class_{32}$. There are no unmatched leaf classes. This will always be true of the root node, so we can conclude that downwards iteration through the policy tree can start at the level below the root nodes. The only reason for including the root nodes would be if a tree were allowed to have multiple root nodes.

At the second level, the leaf classes are assigned to second level nodes as follows:

7, 8 to $Class_2$

9, 10, 11, 12 to $Class_1$

24, 32, 33, 35 to $Class_{20}$

28, 29 to $Class_{22}$

The pair of nodes with the greatest number of equivalent leaf classes in common is $Class_1$ and $Class_{20}$ followed by $Class_2$ and $Class_{22}$:

9, 10, 11, 12 and 24, 32, 33, 35

7, 8 and 28, 29

All of the leaf classes assigned to each node are associated with an equivalent leaf class assigned to the other node of the respective pairs, so nothing is discarded at this level either.

Consider the third level assignments:

9, 10, 11 to $Class_3$

12 to $Class_4$

32 to $Class_{23}$

33, 35 to $Class_{25}$

The best pairing of nodes is $Class_3$ and $Class_{25}$:

9, 10, 11 and 33, 35

Of these five classes, 9, 33 and 10, 35 are equivalent leaf class pairs. This leaves $Class_{11}$ that can't be matched up, because its equivalent leaf class $Class_{32}$ is a descendant of a different third level node $Class_{23}$. As a result the equivalent leaf class pair 11, 32 is eliminated as an equivalent leaf class pair.

With all of these classes removed from consideration, the only class left is 12, so it can't be matched with anything. Since it can't be matched with anything at the third level, the equivalent leaf class pair 12, 24 is eliminated as an equivalent leaf class pair.

The final result of matching is the determination that the following equivalent leaf class pairs have the same parent lineage and can considered unchanged or modified:

9, 33

10, 35

7, 28

8, 29

They and their ancestor classes will be retained, and only modified, during deployment of the new policy.

When equivalent leaf classes are resident at different levels in the old and new policy trees, they will always be eliminated. They may share the same parent classes down through the one leaf class of the pair that is resident at the higher level in either the old or new tree. When iteration reaches the lower leaf class of the pair however, the higher leaf class will no longer be shown as being associated with any node in the other tree at the deeper level, because no node at the deeper level in the other tree can have the higher node as a descendant. This will always result in the pair being eliminated, if they are not eliminated for other reasons.

4.3.3.2 Array-Based Node Matching Technique

Another technique for finding the best matching pairs of nodes involves:

1. Start with the second level of the old and new policy trees.
2. Create an empty array with one row for each node in the old policy tree at the current level and one column for each node in the new policy tree at the current level.

3. Put the number of equivalent leaf class pairs shared by each pair of nodes in the old and new policy trees at the current level into the matrix.

4. Find the entry with the highest number in the matrix

5. Once that number is found, the corresponding pair of nodes is deemed to match

6. Eliminate the row and column from the matrix containing the entry with the highest number

7. Repeat steps 4 through 6 until either the matrix disappears (all rows and columns have been eliminated) or all entries contain 0.

8. Repeat steps 2 through 7 for each level of the old and new policy trees where one of the trees has at least one lower level i.e. do not perform these steps for the lowest level of the deepest tree.

In the above example, the following table was given:

	$Root_0$	$Root_{19}$
oot Level	7, 8, 9, 10, 11, 12	24, 28, 29, 32, 33, 35
nd Level	7, 8 9, 10, 11, 12	24, 32, 33, 35 28, 29
rd Level	9, 10, 11 12	32 33, 35

Table 6: Equivalent Leaf Class Groups

From before, this table indicates the groups of class assignments to a common parent:

- Classes 7, 8, 9, 10, 11, 12 have a common parent at the root level ($Root_0$)
- Classes 7, 8 have a common parent at the 2nd level ($Class_2$)
- Classes 9, 10, 11, 12 have a common parent at the 2nd level ($Class_1$)
- Classes 9, 10, 11 have a common parent at the 3rd level ($Class_3$)
- Class 12 has a parent at the 3rd level ($Class_4$)

- Classes 24, 28, 29, 32, 33, 35 have a common parent at the root level ($Root_{19}$)
- Classes 24, 32, 33, 35 have a common parent at the 2nd level ($Class_{20}$)
- Classes 28, 29 have a common parent at the 2nd level ($Class_{22}$)
- Class 32 has a parent at the 3rd level ($Class_{23}$)
- Classes 33, 35 have a common parent at the 3rd level ($Class_{25}$)

As mentioned in the summary of the algorithm, each level must be processed separately. At the second level a matrix is created for the five nodes in the old and new policy trees:

	$Class_{20}$	$Class_{21}$	$Class_{22}$
$Class_1$	4	0	0
$Class_2$	0	0	2

Table 7: Second Level Matrix

$Class_1$ and $Class_{20}$ share the equivalent leaf class pairs:

11, 32

9, 33

10, 35

12, 24

so their entry in the array has a value of 4. Similarly, $Class_2$ and $Class_{22}$ share the equivalent leaf class pairs:

7, 28

8, 29

so their entry in the array has a value of 2. As there are only 6 equivalent leaf class pairs, all other array entries are 0.

The next step is to find the largest value in this matrix. In this case the value is 4, so $Class_1$ and $Class_{20}$ are designated as being equivalent. The $Class_1$ row and the $Class_{20}$ column of the matrix are eliminated to leave:

	$Class_{21}$	$Class_{22}$
$Class_2$	0	2

Table 8: Revised Second Level Matrix

The next largest value is 2, so $Class_2$ and $Class_{22}$ are designated as being equivalent. Once the $Class_2$ row and the $Class_{22}$ column have been eliminated, the matrix has disappeared, so level 2 of the policy trees has been completed.

At the third level, the following matrix is created:

	$Class_{23}$	$Class_{25}$
$Class_3$	1	2
$Class_4$	0	0
$Class_5$	0	0
$Class_6$	0	0

Table 9: Third Level Matrix

$Class_3$ and $Class_{23}$ share the equivalent leaf class pairs:

11, 32

while $Class_3$ and $Class_{25}$ share the equivalent leaf class pairs:

9, 33

10, 35

Notice that the other three equivalent leaf class pairs are not represented in the level 3 matrix. This is because $Class_7$ and $Class_8$ in the old policy tree and $Class_{24}$, $Class_{28}$, and $Class_{29}$ in the new policy tree reside at level 3 and are not children of level 3 classes.

The largest value in this matrix is the value 4, so $Class_3$ and $Class_{25}$ are designated as being equivalent. The equivalent leaf class pair 11, 32 shared by $Class_3$ and $Class_{23}$ is eliminated from consideration as an equivalent leaf class pair. The $Class_3$ row and the $Class_{25}$ column of the matrix are eliminated to leave:

	$Class_{23}$
$Class_4$	0
$Class_5$	0
$Class_6$	0

Table 10: Revised Third Level Matrix

Since there are no non-zero entries, the third level has been completed. The fourth level of the old and new policy trees consist only of leaf classes, so the overall method has also finished.

It will be noticed that this method confirms the equivalency of equivalent leaf class pairs as a side effect of selecting an array entry with the highest value.

It may also be noticed that the matrix method does not detect equivalent leaf classes that are at different levels of the old and new policy trees. If the matrix method is used, these leaf classes can be eliminated either by a simple comparison of tree level when they are first proposed as being equivalent (e.g. by incorporating policy level into the comparison function or hash function), or they can be detected as a side effect of constructing array entries.

Marking Classes as being Modified, Unchanged, Added Or Deleted

The previous section showed how equivalent ancestor classes are identified and how proposed equivalent leaf class pairs are confirmed as being equivalent or are eliminated as being equivalent. Once the above step has been completed, the next step is to mark each class in both policy trees as:

- Unchanged
- Modified
- Added
- Deleted

All equivalent ancestor classes and confirmed equivalent leaf classes found by the methods of the previous section are marked as being either unchanged or modified. The choice of marking these classes as either unchanged or modified depends on whether a pairwise comparison of equivalent classes indicates whether they have any differences.

Consider the same two policies that were used as an example in the previous section. Using either of the methods in that section it was discovered that the following classes were equivalent:

- $Root_0$ and $Root_{19}$
- $Class_1$ and $Class_{20}$
- $Class_2$ and $Class_{22}$
- $Class_3$ and $Class_{25}$

- $Class_7$ and $Class_{28}$
- $Class_8$ and $Class_{29}$
- $Class_9$ and $Class_{33}$
- $Class_{10}$ and $Class_{35}$

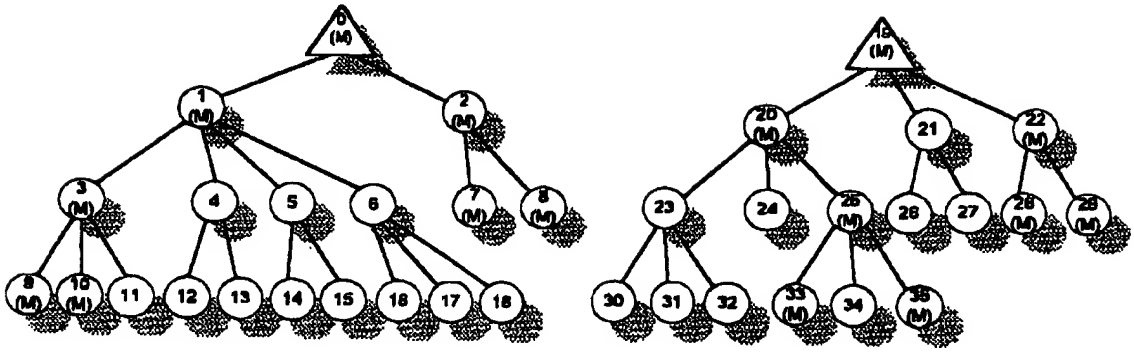


Figure 21: Marking Classes As Modified

A class with (M) indicates that it has been marked as modified. If equivalent classes were truly identical, they would be marked as unchanged instead.

As a side effect of marking equivalent classes as being modified or unchanged, the class identifiers for the class in the old policy tree will be reused for the equivalent class in the new policy tree. The class identifiers identify data structure entries for classes in the classification engine and packet scheduler. It is important to reuse the class identifiers to minimize the disruption of converting from the old policy tree to the new policy tree.

The next step is to mark the rest of the old policy as being deleted:

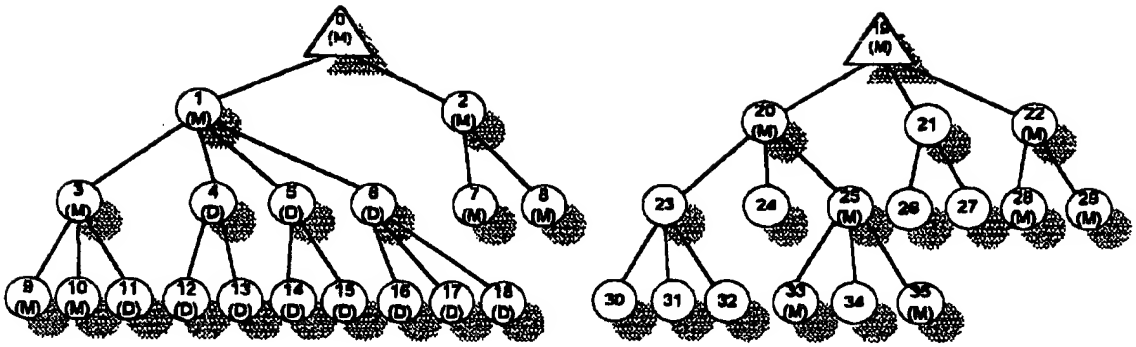
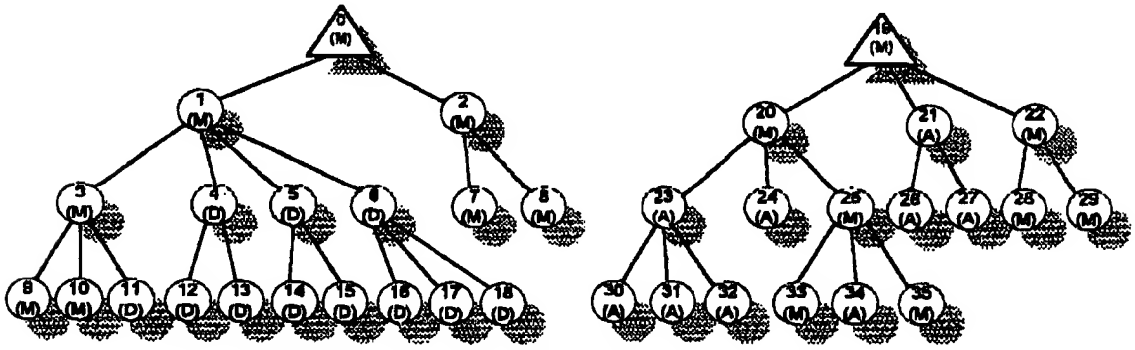


Figure 22: Marking Classes As Deleted

A class with (D) indicates that it has been marked as deleted.

The next step is to mark the rest of the new policy as being added as shown in figure 23:

Figure 23: Marking Classes As Added



A class with (A) indicates that is has been marked as added.

It should be noted that the example resulted in relatively few classes being marked as modified or unchanged. In practical network situations, policies tend to evolve as a series of minor changes. The differences between an old and new policy tend to be minor. The overall policy differentiation method described in this document is quite valuable for minimizing the amount of disruptive changes in transitioning from the old policy to the new policy.

As will be apparent to those skilled in the art in the light of the foregoing disclosure, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof.

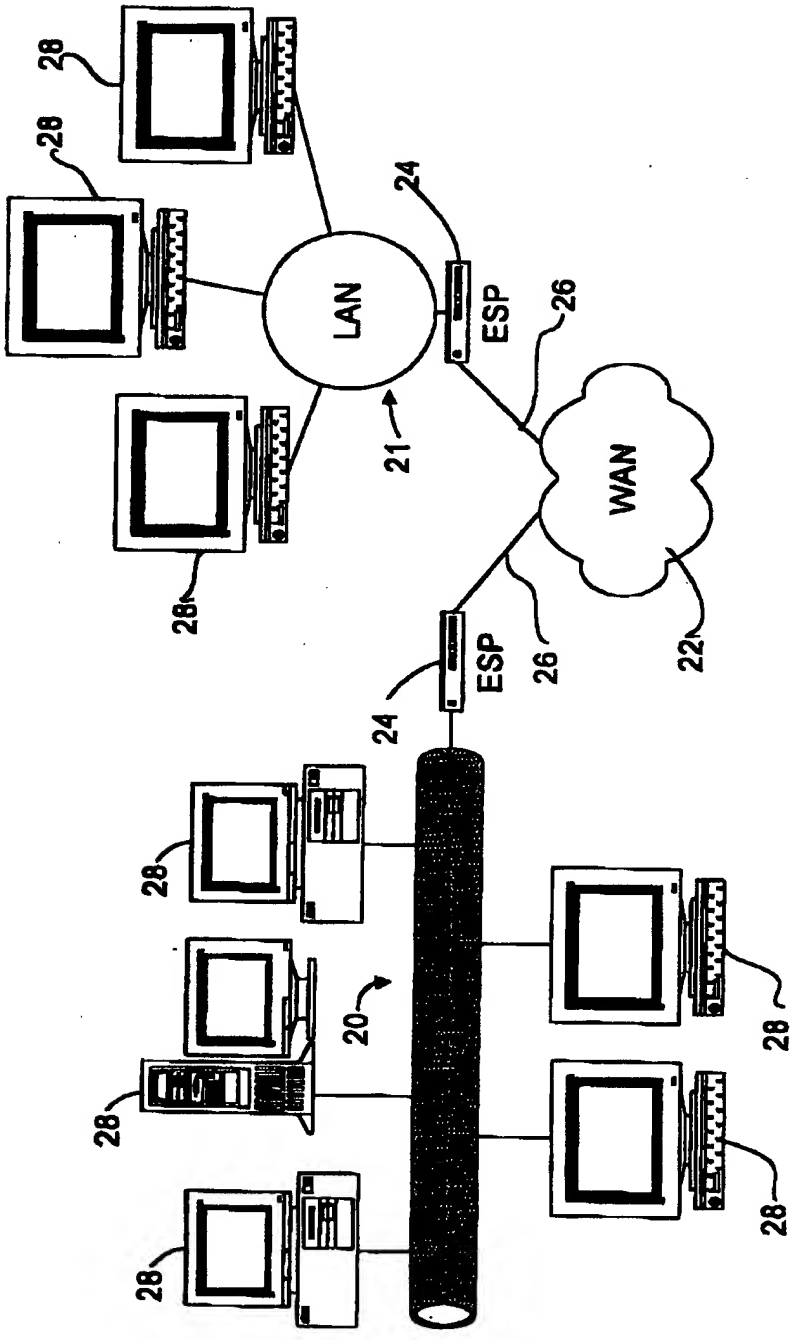


FIG 1.

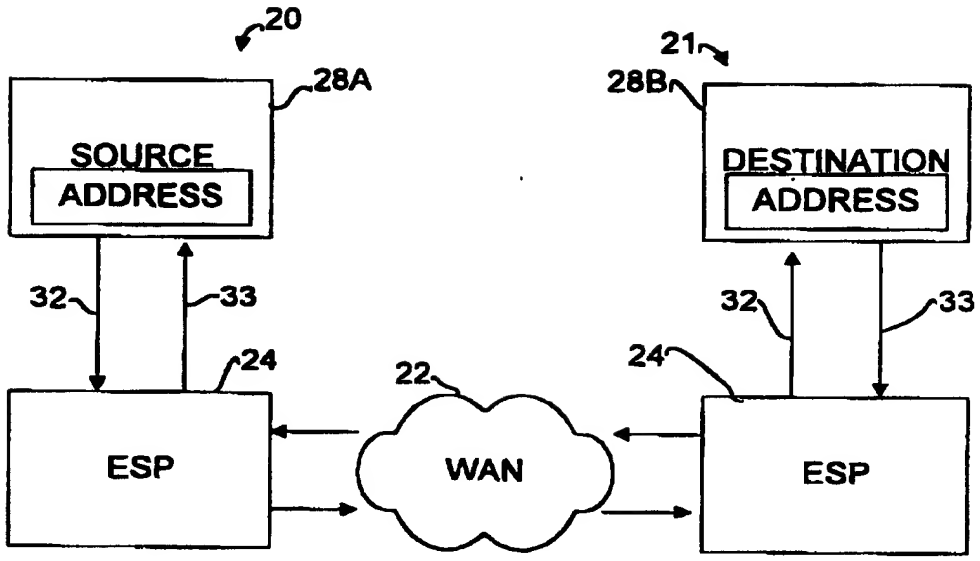

20
21
28A
28B
SOURCE
ADDRESS
DESTINATION
ADDRESS
32
33
32
33
24
22
24
ESP
WAN
ESP

FIG 2

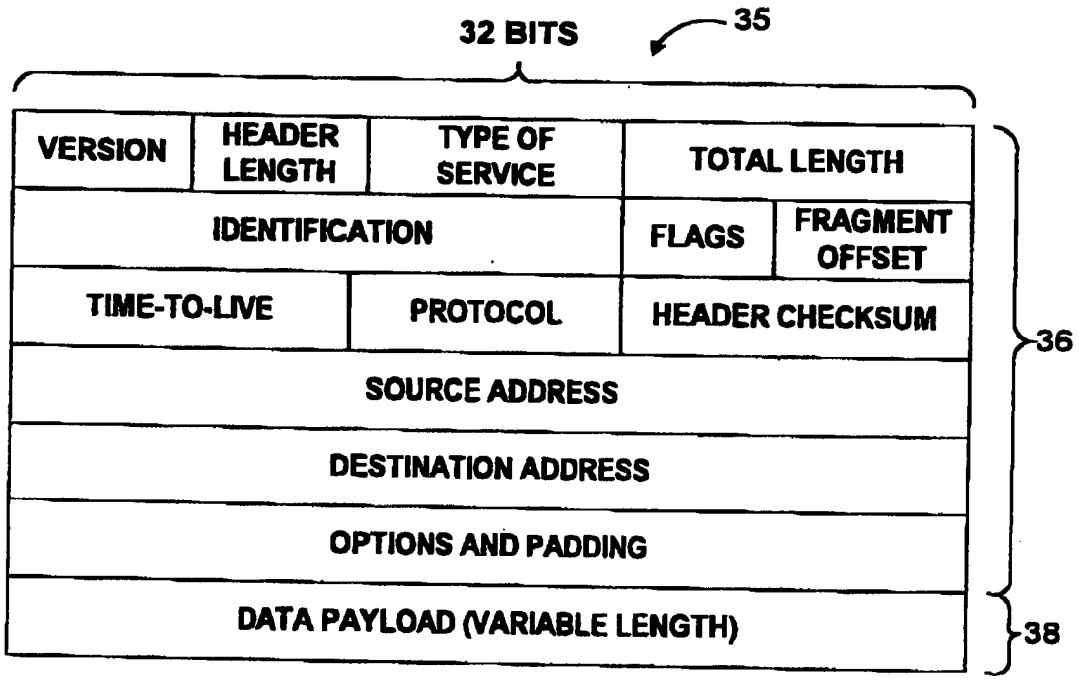

32 BITS
35
VERSION
HEADER LENGTH
TYPE OF SERVICE
TOTAL LENGTH
IDENTIFICATION
FLAGS
FRAGMENT OFFSET
TIME-TO-LIVE
PROTOCOL
HEADER CHECKSUM
SOURCE ADDRESS
DESTINATION ADDRESS
OPTIONS AND PADDING
DATA PAYLOAD (VARIABLE LENGTH)
36
38

FIG 3

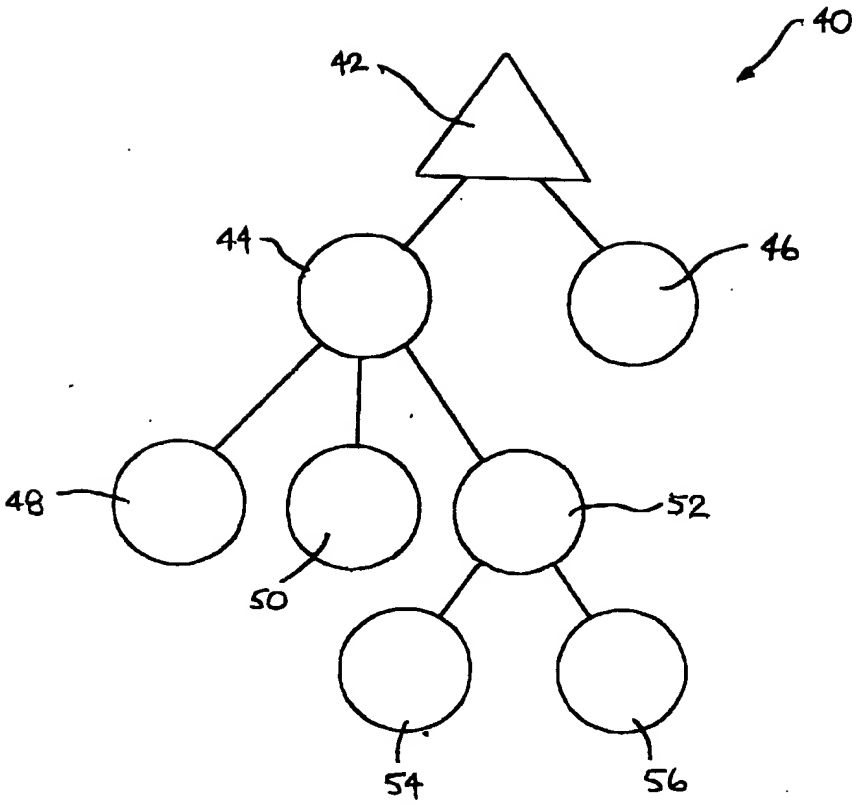


FIG. 4

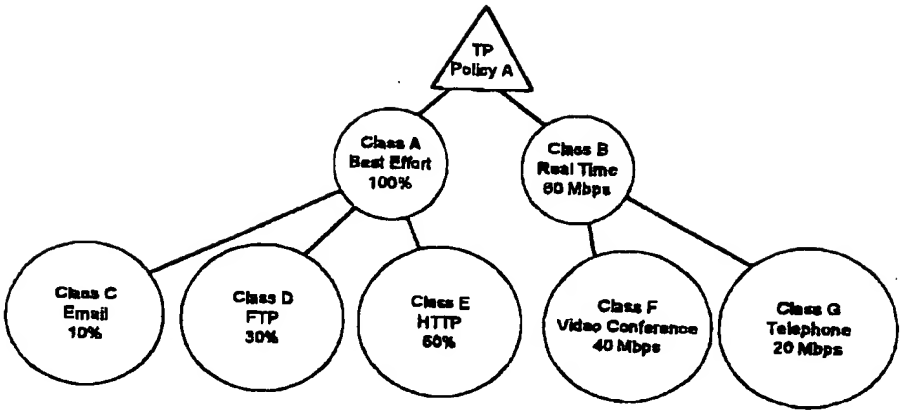

TP
Policy A
Class A
Best Effort
100%
Class B
Real Time
60 Mbps
Class C
Email
10%
Class D
FTP
30%
Class E
HTTP
60%
Class F
Video Conference
40 Mbps
Class G
Telephone
20 Mbps

FIG. 5

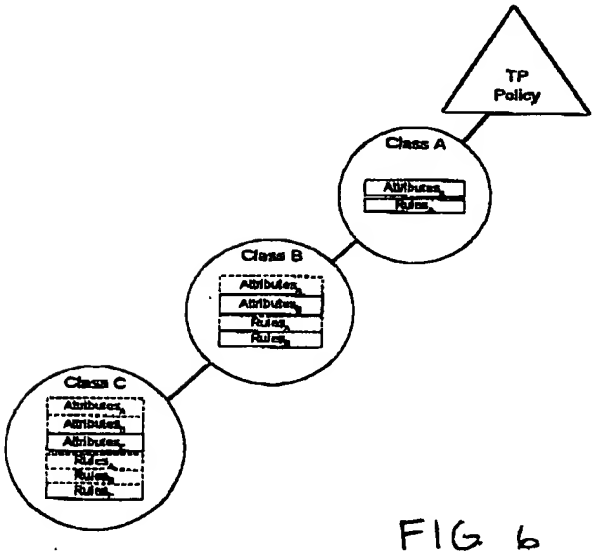
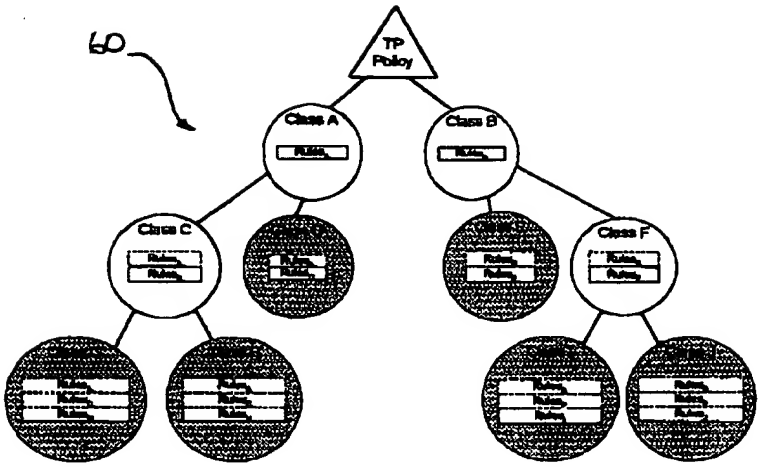

TP
Policy
Class A
Class B
Class C

FIG 6



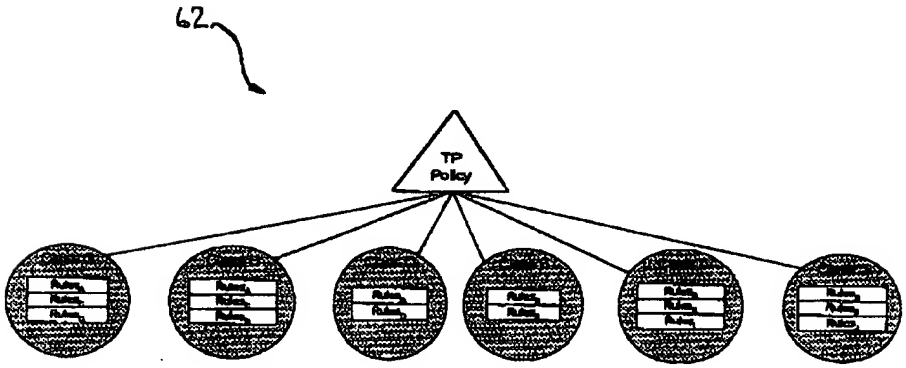


FIG. 7

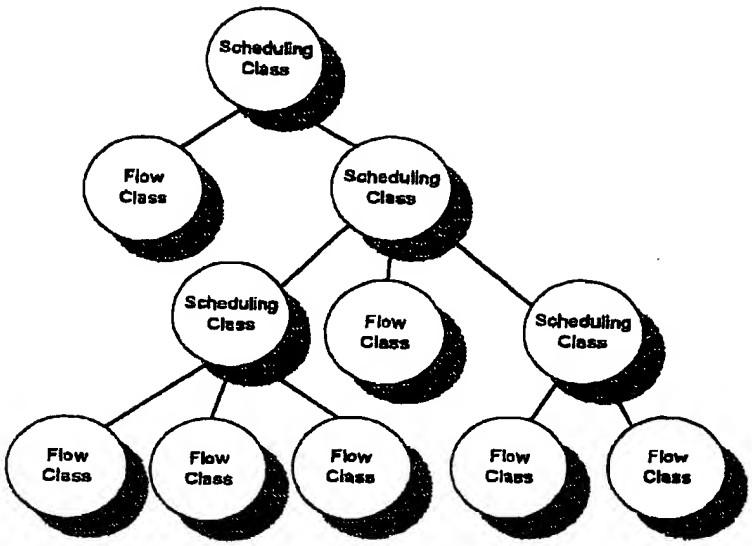

Scheduling Class
Flow Class
Scheduling Class
Scheduling Class
Flow Class
Scheduling Class
Flow Class
Flow Class
Flow Class
Flow Class
Flow Class

FIG. 8

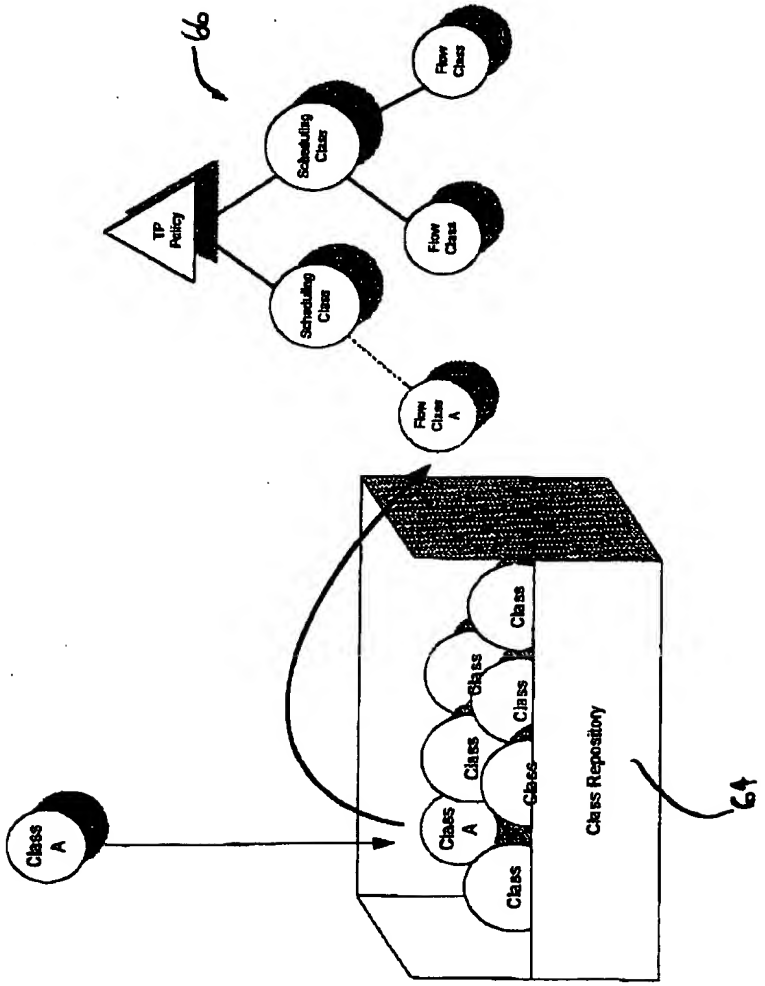

66
Flow Class
Scheduling Class
TP Policy
Flow Class
Scheduling Class
Flow Class A
Class
Class
Class
Class
Class
Class A
Class
Class Repository
64
Class A

FIG. 9

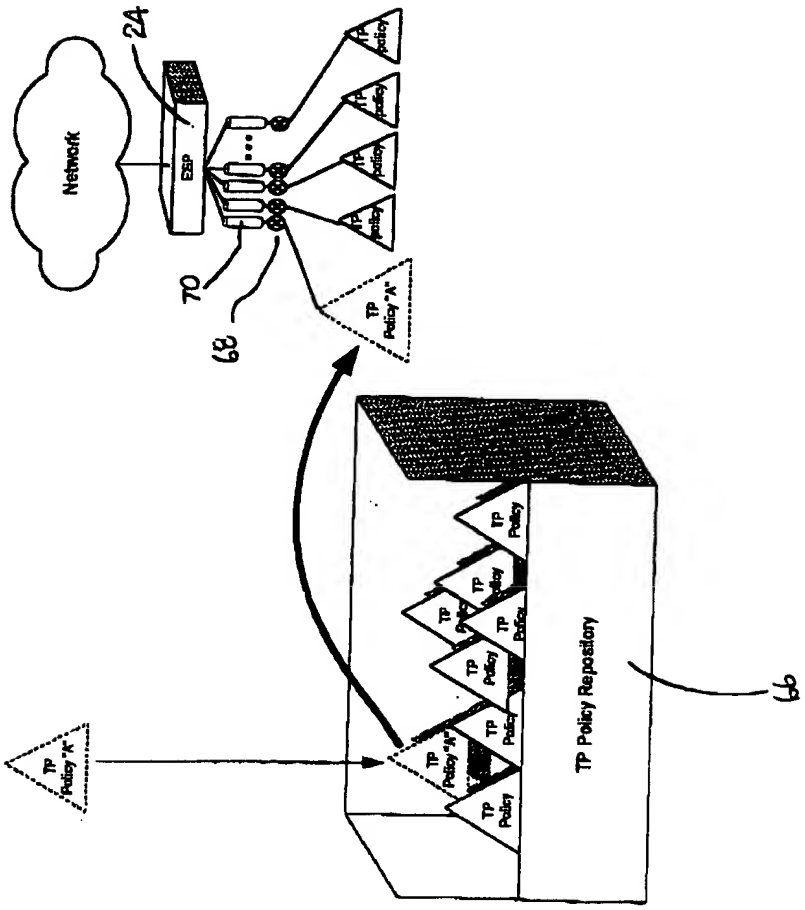

24
Network
ESP
70
68
TP Policy "A"
TP Policy
TP Policy Repository
96

FIG. 10

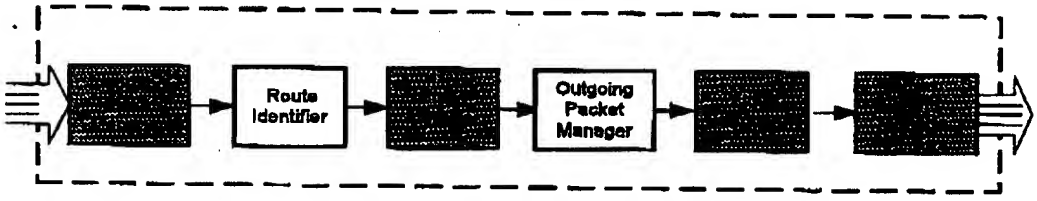

Route Identifier
Outgoing Packet Manager

FIG. 11

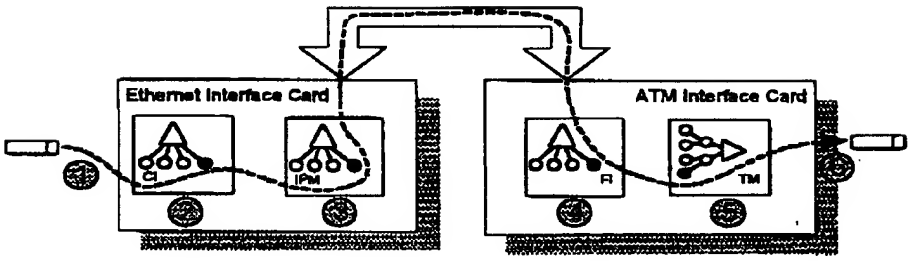

Ethernet Interface Card
IPM
ATM Interface Card
FI
TM

FIG. 12

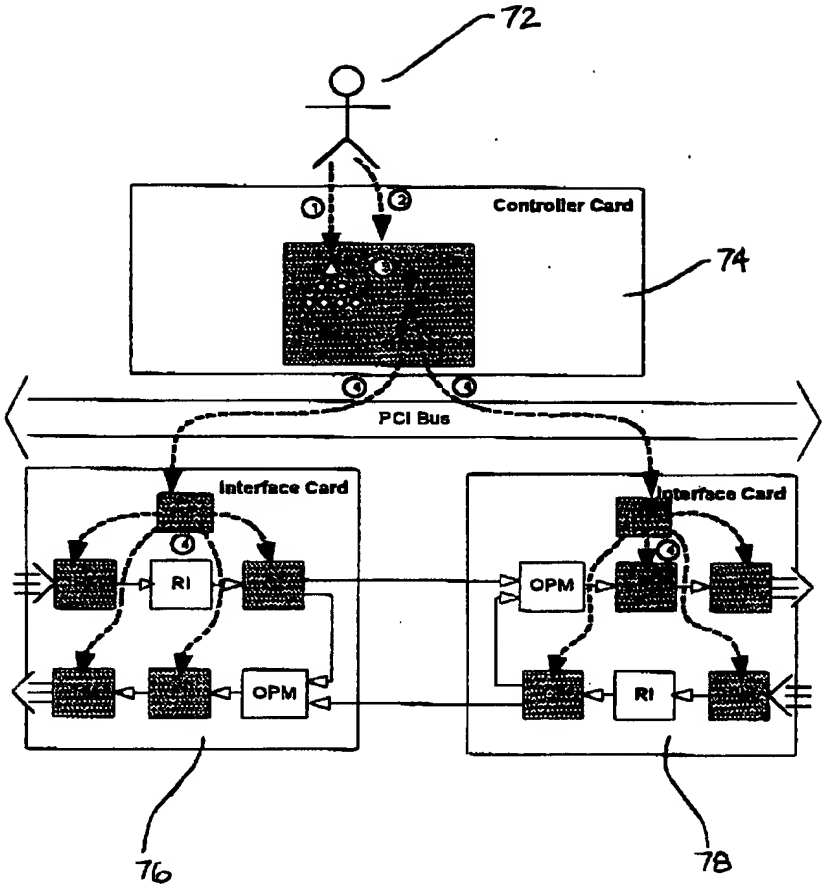

72
Controller Card
74
PCI Bus
Interface Card
RI
OPM
OPM
RI
Interface Card
76
78

FIG. 13

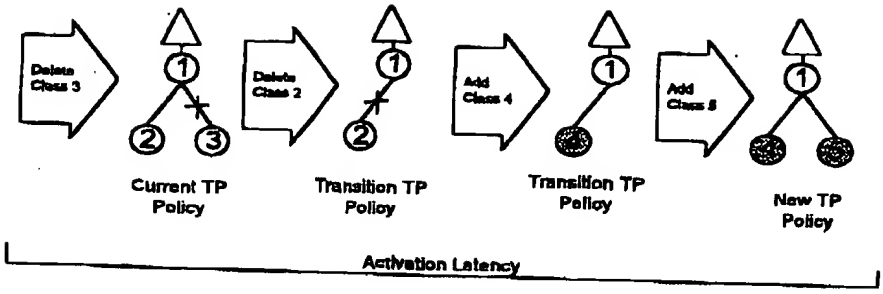

Delete Class 3
Delete Class 2
Add Class 4
Add Class 5
1
2
3
Current TP Policy
Transition TP Policy
Transition TP Policy
New TP Policy
Activation Latency

FIG. 14